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Consumers’ confidence in a business cycle model: an agent-based approach

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DECLARATION

I declare that I wrote the doctoral dissertation myself, including the attachments. I have included all information sources in the list of references and have cited them appropriately in the doctoral dissertation.

In Ostrava on 8.8.2017

Signature

Abstrakt

Vliv důvěry na vývoj ekonomické aktivity zdůrazňoval již Keynes (1936), který o něj opřel své úvahy o možnostech fiskální politiky stimulovat agregátní poptávku v období slabé ekonomické aktivity. Později byl tento vliv prokázán i v několika empirických studiích (Mueller, 1966, Ludvigson, 2004, aj.). Cílem této disertační práce je zjistit, zda v rámci vlivu důvěry na ekonomickou aktivitu nemůžeme postoupit ještě dále, zda může šíření vln optimismu či pesimismu ve společnosti vést nejen k ovlivnění ekonomické aktivity, ale rovněž způsobovat její cyklické výkyvy.

Podobnou úvahou se zaobíral již Westerhoff (2010), na jehož práci částečně navazujeme. V modelu Westerhoffa (2010) je sentiment vztažen k produkčním jednotkám. Jednotlivé produkční jednotky formují na základě sentimentu svá očekávání ohledně agregátní poptávky a dle očekávání dále stanovují výši své produkce. Westerhoff (2010) prokázal, že šíření vliv optimismu a pesimismu mezi produkčními jednotkami může generovat cyklické chování ekonomické aktivity.

V rámci disertační práce se však zaobíráme důvěrou ze strany spotřebitele. Role důvěry je zde přesunuta do formování spotřebitelských výdajů a určuje agregátní poptávku. Konkrétním cílem práce je zjistit, zda šíření vln optimismu a pesimismu mezi spotřebiteli může vést k cyklickému chování ekonomické aktivity.

K posouzení tohoto cíle je v práci využito postupů multiagentního modelování. V rámci práce byl sestaven jednoduchý model se sítí agentů - spotřebitelů, na níž je simulováno šíření vln optimismu či pesimismu. Kromě této sítě je v modelu přítomna jedna produkční jednotka - firma. Model je dále za účelem sledování vlivu důvěry zaměřen na vývoj agregátní poptávky a nabídky, neobsahuje monetární autoritu a předpokládá konstantnost cen. Vliv šíření spotřebitelské důvěry je dále posuzován i na pokročilejším modelu. Tento model je rozšířením základního modelu o heterogenní trh práce. Cílem tohoto rozšíření je zohlednění vlivu míry nezaměstnanosti na spotřebitelovu důvěru. Simulace obou modelů potvrdily, že šíření vln optimismu i pesimismu v důvěře spotřebitelů mohou vést k cyklickému chování ekonomické aktivity.

Abstract

The importance of confidence was already emphasized by Keynes (1936), who used it to support his reasoning on the potential of possible fiscal policies to stimulate aggregate demand during the times of weak economic performance. The influence of confidence on economic activity was later confirmed in many empirical studies (Mueller, 1966, Ludvigson, 2004, etc.). The main goal of this dissertation thesis is to find out, whether the impact of the economic confidence on economic activity could be even larger, if the spread of waves of optimism and pessimism in society could not only influence the economic activity but also cause its cyclical movement.

Similar idea was already presented by Westerhoff (2010) and we are partially continuing in his work. In the model of Westerhoff (2010) the confidence is related to production units. Each production unit is, on the base of its confidence, forming its expectations about the aggregate demand and according to these expectations they determine its production. Westerhoff (2010) proved that the spread of the waves of optimism and pessimism, among production units, can generate the cyclical movement of economic activity.

In the dissertation thesis, we are considering the role of confidence from the side of a consumer. The confidence is connected here with the formation of consumption spending and determines the aggregate demand. The concrete goal of the thesis is to find out, whether the spread of waves of optimism and pessimism among consumers could lead to a cyclical movement of economic activity.

The research is undertaken using agent-based modelling. Within the thesis, we have constructed a simple agent-based model with a lattice of agents - consumers, on which a spread of confidence is simulated. Besides the lattice, there is one production unit - firm in the model. The model is focused on the development of an aggregate demand and an aggregate supply to monitor the influence of confidence. There is no monetary authority and the prices are assumed to be constant. The influence of the spread of the consumers' confidence was further assessed on more complex model. This model is an extension of the baseline model for a heterogeneous labor market. The goal of this extension is to consider the influence of an unemployment rate on the consumer confidence. Simulations from both models confirmed that the spread of waves of optimism and pessimism can really generate the cyclical movement of economic activity.

Contents

1 Introduction

After the boom and the recent Great Recession in the US economy, also quickly spreading around the European economies, a lot of economists found out that the role of the confidence in the society could be crucial. Thus, the role of the confidence in the society came into the center of attention. The primal role of the confidence in the society is obvious - without any trust between two trading partners no trade could be done, without the confidence in protection of property hardly any good would be bought. One of the roles of government and the functional law system is the establishment of the economic environment where these basic principles of the confidence are assured.

However, the role of confidence in the society could go deeper, as was already emphasized by Keynes (1936). According to him, the confidence on the side of firms could support investment, the confidence on the side of consumers the aggregate demand. With the high level of confidence the economy could be, according to Keyenes (1936), successfully drawn out from the recession to the growth anew. The role of the confidence is emphasized in the case when the economy is in its bottom. What could be the role of confidence when the economy is at its peak? We have already witnessed that in the case of US financial crisis. The level of confidence on the market of mortgages started to rapidly fall from its high level, taking down the whole economy. Thus, we can take into the consideration that the role of confidence could be connected with the business cycle movement in the economy.

Following the idea of the importance of consumer confidence, we would like to investigate the spread of confidence and its impact on the economic activity. Taking into consideration that Taylor and McNabb (2007) proposed to use the consumer confidence to determine turning points of the business cycles and Howrey (2001) and Haugh (2005) confirmed its significance mainly for predicting recessions or recoveries, we would like to concentrate also on the relationship between confidence measure and economic activity within the business cycle. More precisely, we would like to find out if the spread of optimism/pessimism in the consumer confidence can lead to a cyclical movement of economic activity.

The suitable way how to model the influence of the consumer confidence on the economic activity is still disputable. The confidence is individual and heterogenous among consumers, related to the consumer's environment on the micro level. The economic activity is on the other side examined from the macro level. Modelling the economic activity on the aggregate level means to try to track the evolvement of the economy in the environment of society, a complex system which is, according to Hayek (1973), subordinated to spontaneous order. Hayek (1973, p.41) claims that: "Since a spontaneous order results from the individual elements adapting themselves to circumstances which directly affect only some of them, and which in their totality need not to be known to anyone, it may extend to circumstances so complex that no mind can comprehend them all. Consequently, the concept becomes particularly important when we turn from mechanical to such 'more highly organized' or essentially complex phenomena as we encounter in the realms of life, mind and society. Here we have to deal with 'grown' structures with a degree of complexity which they have assumed and could assume only because they were produced by spontaneous ordering forces."

The first attempts to introduce the confidence into the macroeconomic modelling was through time series analysis. Although, the importance of confidence was confessed by Keynes (1936), due to a difficulty in its measurement, it was not considered in macroeconomic modelling for a long time. Nowadays, with the technical development and wider statistical possibilities, the economic confidence in the society is measured by questionnaires. On the basis of these indicators, the importance of the economic confidence for modelling the development of economic activity (measured by GDP) was already confirmed by Mueller (1966) and Ludvigson (2004), etc. Carrol, Fuhrer and Wilcox (1994), Throop (1992), Acemoglu and Scott (1994), Bram and Ludvigson (1998) and Souleles (2001) confirmed the significance of confidence indicator also for predicting the consumption growth. On the other hand, Al-Eyd, Barrell and Davis (2009), Cotsomitis and Kwan (2006) stated that its role in prediction of future consumption spending after controlling for other measurable macroeconomic variables is, at least, limited. Dees and Brinca (2013, p.2) stated that "while the evidence is overall rather mixed, most authors seem to, at least, find a significant statistical relationship between confidence measures and economic variables, current and future." Lahiri et al. (2016) reexamined the existing empirical models on consumption and consumer confidence with the result in favor of consumer confidence' significance.

The partial explanation of these seemingly mixed results could be that the consumer confidence is not always significant, but rather in some phases of the business cycle. Dees and Brinca (2013) used threshold models and argued that the importance of confidence is increased when only large changes in confidence are considered. Howrey (2001) and Haugh (2005) stated that the confidence indicator is significant in predicting recessions or recoveries. According to Taylor and McNabb (2007), the consumer confidence grows and falls with the economic activity (develops procyclically) and could be used to determine turning points of the business cycles.

The joint feature of these studies is that the significance of consumer confidence for modelling consumption spending was tested by autoregressive (AR) or vector autoregressive (VAR) models applied on macroeconomic data. This is, undoubtedly a common and very practical method because it is quite simple, based on real macroeconomic data, which are generally available, and often allows us to make high quality predictions (in terms of high explained variation of the model). However, it is questionable whether the impact of consumer confidence on consumption spending could be investigated at the aggregate level, from the macroeconomic perspective, or, better directly from the microeconomic level. Secondly, the above mentioned studies were mainly assuming the linear relationship between the consumer confidence and the consumption growth. The results of Dees and Brinca (2013) from threshold models support the idea that the relationship could be nonlinear.

The alternative and very common approach in macroeconomic modelling is the dynamic stochastic general equilibrium (DSGE) approach. DSGE models are still simulating the development of the economy on macroeconomic variables, but they have built-in microeconomic structures. Standard DSGE models, like the model of Smets and Wouters (2003), do not consider the economic confidence. Some new DSGE models are trying to nest the confidence into models through consumers' expectations. Argentiero et al. (2015) constructed a DSGE model with psychological bias in expectations and presented that the DSGE model with the over optimistic agents perform better in the long run and in the phases of economic booms.

What seems to be a viable alternative for modelling consumer confidence is a relatively new approach called agent-based computational economics (ACE)[1]. In ACE macroeconomic structures are modelled "from the bottom up", e.g. the macroeconomic features of the economy are emerging from the simulations on a micro level. This approach could very well reflect the spontaneous order presented by Hayek (1973), because it is focused on setting of individual rules only and the evolement of the system is generated by the spontaneous order based on the interactions among individuals within the defined system.

The development of the economy in ACE model is simulated on the lattice of agents. These agents are following microeconomic rules and interact among themselves. The big advantage of modelling consumer confidence in ACE model is that confidence could be directly assigned to each consumer and incorporated in the model on the microeconomic level. The second big advantage is that, as the relationship between confidence and consumption spending emerges from the interactions, there is no need (and not even possible) to specify the linearity/nonlinearity of this relationship on the aggregate level. Thus, the model is suitable even for nonlinear relationships on the aggregate level. Further, by use of ACE model we are no more limited to work with the data on the aggregate level. Thanks to the construction of the model, we can work with heterogeneous agents and track the spread of the confidence and the consumption spending on the individual level. De Giorgi and Gambetti (2015) already showed that we can fit the business cycle movement in the aggregate consumption quite well by using microdata of heterogeneous consumers.

Following the advantages and possibilities of this approach, we have decided to model the spread of confidence and its impact on the economic activity within the ACE model. However, the interest for agent based models is growing, their application in economics is, for its novelty and complexity, still rare. Until now, there were only few ACE models for the whole economy constructed in the European Union. According to our knowledge, such a model was not constructed in the Czech Republic yet. The few ACE models in the European Union or in the Czech Republic are usually focusing on just a part of the economy, not the complete system. Thus, construction of the ACE model for the whole economy is still a big novelty

[1]The first agent-based model focused on the social phenomena was introduced by Shelling (1971). The conference proceedings about the application of agent-based models in behavioral or social science have been presented since the early nineties, for example, by Gilbert and Doran (1994) or Gilbert and Conte (1995).

in the field of macroeconomic modelling.

The main goal of the thesis is to find out, whether the spread of the waves of optimism/pessimism in consumer confidence in an ACE model could generate an endogenous cyclical movement of economic activity. Slightly similar problem was already investigated by Westerhoff (2010), who constructed an ACE model and modelled the spread of waves of optimism/pessimism in confidence of firms. The confidence of other firms was one of the factors in determining the supply of a firm. It had a direct impact on the aggregate supply and the spread of the waves of optimism/pessimism generated the cyclical behavior of aggregate income. In this disertation, we would like to investigate if the confidence of consumers could cause the endogenous economic cycle through the aggregate demand.

To achieve this main goal, the following partial goals were defined:

- **The first partial goal is to find out, whether the spread of the waves of confidence could lead to a cyclical movement of aggregate demand**. Investigating this goal will help us to support the propagation mechanism of consumer confidence. The results of this partial goal can also contribute to recent results about the significance of consumer sentiment for forecasting consumption spending.

- **The second partial goal is to find out, whether the spread of the waves of confidence could lead through the cyclical movement of aggregate demand to the cyclical movement of economic activity, within a simple ACE model with uniformly distributed income.** The propagation mechanism of consumer confidence and its impact on economic activity will be presented using a simplified ACE model.

- **The last partial goal is to find out, whether the spread of the waves of confidence could generate an endogenous cyclical movement of economic activity within the ACE model with a heterogeneous labor market.** According to Mueller (1966) and Malley and Moutos (1996), there exists a strong negative influence of the rate of unemployment on consumer confidence. As the consumer confidence in the model is an endogenous variable, the effect of the unemployment rate on it should be considered. Therefore, the simplified ACE is extended for the heterogeneous labor market with unemployed agents. The effect of the rate of unemployment on the consumer confidence could be expressed directly, by adding a new parameter in the simulation part of consumer confidence, or indirectly, through the decreased income of the unemployed agent and hence, the higher probability of being a pessimist for him/her and his/her neighbors. We have constructed an extended version of the ACE model with a heterogeneous labor market and indirect effect of the unemployment on the consumer confidence. The implementation of direct impact requires a deeper analysis of the size and a form of this impact and could be a possible way for future work in modelling consumer confidence.

The structure of the dissertation thesis is following. Firstly, the motivation of the dissertation thesis, which concentrates on the definition of the consumer confidence, its measurement and its role in consumer behavior, will be presented in Chapter 2. The discussion of the possible methods and deeper description of agent-based modelling will be provided in Chapter 3. The simple agent-based model with the spread of economic confidence among consumers together with its simulation results and sensitivity analysis is presented in the Chapter 4. The extended version of this model with the heterogeneous labor market will be described in Chapter 5 (the simulation results and the sensitivity analysis is included, too). Chapter 6 concludes. The lists of model variables and equations from both models together with the code of the baseline model can be found in Appendices. The code of both models together with their sensitivity analysis is attached on CD.

2 The consumer confidence

This chapter will be dealing with the definiton of the consumer confidence, its reflection in consumer's behavior, the role of confidence during the business cycle and its role in the macroeconomic model.

2.1 The definition and the measurement of the consumer confidence

Potter (1999, p.6) defines, in his paper, a confidence in generally in the following way: "The level of certainty about the unobserved factor is interpreted as confidence." The definition of consumer confidence is than more specific. According to the Conference Bord (cited in McWhinney (2004)) "the consumer confidence, measured by the Consumer Confidence Index (CCI), is defined as the degree of optimism on the state of the economy that consumers (like you and me) are expressing through their activities of saving and spending." The Federal Reserve Bank of St. Luis (2016) define consumer confidence as "A measure of how consumers feel about the economy, considered an indicator of consumers' spending and saving decisions". Although, there are a lof of organizations which are trying to measure the consumer confidence nowadays, they do not usually explicitly define consumer confidence or sentiment but rather directly their constructed indicator for it.

In the US, the two most important indicators for consumer confidence is the University of Michigan Consumer Sentiment Index and the Consumer Confidence Index. The University of Michigan Consumer Sentiment Index is measured from 1946 within the surveys of consumers. The Consumer Confidence Index is measured on monthly basis from 1967. The Conference Board (2011, p.1) describes it as "a barometer of the health of the U.S. economy from the perspective of the consumer. The index is based on consumers' perceptions of current business and employment conditions, as well as their expectations for six months hence, regarding business conditions, employment, and income." Both indices are calculated from the responses to survey questiones. The broader description of the methodology and comparison of these two indexes was done by Ludvigson (2004). In Europe, the measurement of the consumer confidence is unified by The Joint Harmonised EU Programme of Business and Consumer Surveys, designed by European Commission (2016). The cross-country measurements for worldwide pool of countries on the half-annual basis is provided by Nielsen Global Online Consumer Survey. The consumer confidence is further measured, for example, in Canada or India and is slowly becoming a part of countries' satistical surveys.

2.2 The reflection of confidence in consumer's behavior

The usefulness of consumer confidence indicator for modelling aggregate consumption spending has already been confirmed, for example, by Carroll, Fuhrer and Wilcox (1994). They used the confidence indicator as a proxy for estimating future streams of incomes for testing the validity of Rational Expectation Permanent Income Hypothesis (Hall, 1978) on the US data. Further, they were testing, whether the consumer confidence remains significant in the prediction of consumption spending even after considering all other information obtained from measurable variables (the rate of unemployment, the interest rate, etc.). They have found out that the confidence indicator is a significant regressor while modelling consumption spending. The contribution of confidence indicator in prediction of consumption spending is not connected only with the estimation of the future stream of incomes. Moreover, the consumer confidence indicator contains an additional information, which could not be covered by other measurable macroeconomic variables.

The role of confidence indicator in prediction of consumption spending was accepted also by Throop (1992), Acemoglu and Scott (1994), Bram and Ludvigson (1998) and Souleles (2001). However, the results about its significance for predicting consumption spending after controlling other measurable macroeconomic variables are slightly ambiguous. Al-Eyd, Barrell and Davis (2009) and Cotsomitis and Kwan (2006) found its role as limited. Lahiri et al. (2016) reexamined the models and explained that the results from previous studies (mainly by Al-Eyd, Barrell and Davis (2009)) suffered from some inaccuracy in models. Firstly, Lahiri et al. (2016) pointed out that the consumer confidence data were with the monthly frequency but consumption spending data with the quarterly one. Averaging of confidence data for quarters could lead to loss of information. Secondly, they argued that the data, which were used, were revised and they proposed to work with the real-time data of consumer confidence. Thirdly, they used a bigger information set in the model. The results from the reestimated models confirmed the significance of consumer confidence for short-term forecasting of consumption spending. We have also tried to estimate the significance of EU harmonized consumer confidence indicator for the growth of consumption spending on panel data of ten member countries of EU, the significance was confirmed for seven (Závacká, 2013b).[2]

As it was already mentioned, the possible reasons for rather ambiguous conclusions about the prediction power of consumer confidence in predicting consumption spending could be explained either by a possible nonlinearity of this prediction power (supported by the threshold model of Dees and Brinca, 2013) or by the change of this prediction power during the business cycle (supported by Taylor and McNabb, 2007, Howrey,2001 and Haugh, 2005). If the prediction power is not linear or is strong only in some phases of the business cycle, the traditional autoregressive models, which are evaluating the relationship between consumer confidence and consumption spending (or between their growth rates) on all data, could reject its statistical significance. As the business cycle movements do not exactly coincide among countries, results derived from the time series analysis of economic activity of different countries could, therefore, vary. Further, the possible explanation for the rather mixed results is that the studies are based on different data. In the studies based on US data, the consumer confidence is approximated for example by Michigan index, while in the case of Europe, the consumer confidence indicator

[2]Similar analysis for the Czech economy was done by Závacká (2013a).

from the European Commission is usually used. Both indicators are based on questionnaires but the questionnaires, as well as, methodologies are different.

2.3 The role of confidence during the business cycle

The role of the confidence has been connected with the forming of expectations, in the business cycle models. The first references to its importance was already presented, for example, in the work of Mill (1844). Marshal (1923) emphasized that the positive change in confidence could cause the growth of the investment and the real exchange rate. This can further support the growth of prices and provoke an overreaction on the optimism in the confidence. The traders start to speculate on the credit growth and cause the new wave of distrust on this market, leading to the spiral fall of prices and dramatic fall in confidence and economic activity.

As well as Marshal (1923), also Pigou (1923) saw the possible psychological factor for the business cycle movement on the side of supply. According to him, the entrepreneurs were constantly making errors in their profit expectations, causing the fluctuations in the investment and further in the economic activity. He presented that the errors of optimism give rise to the errors of pessimism and vice versa. "Hitherto we have considered errors of optimism and pessimism as simple, self-contained and independent. They are not, however, in fact of this character. On the contrary, errors of either sort, in whatever way they may have come about, have the characteristic of generating, after a while, errors of the opposite sort." (Pigou, 1923, p.83) The error of optimism on the side of entrepreneur is in his exaggerated expectations about the future profit. Once this error is recognized, the entrepreneur starts to sell his/her goods for the lower price, experiencing the loss or bankruptcy. This loss is further projected on this creditors and the wave of pessimism in the confidence starts. After that, the error in the pessimism is supporting the new revival of the economy.

Keynes (1936) continued in the business cycle theory based on the errors in optimism and pessimism on the side of entrepreteurs introduced by Pigou (1923) and exteded this theory also for the demand side. According to him, decisions made by consumers are also influenced by the psychological factor. Keynes (1936) explained that consumers are adjusting their marginal rate of consumption with respect to their economic expectations. He accepted, as the main factor causing the business cycle movement, the fluctuations in the investment and proposed to substitute the dropout in the aggregate demand by the investment of the government.

The explanation of the business cycle movement through the errors in optimism and pessimism was later replaced by the introduction of the rational expectations and the role of the confidence was shifted into the form of exogenous shocks. However, the importance of the confidence was further investigated within the behavioral economics for example by Tversky and Kahneman (1974), Arrow (1982) or Akerlof and Shiller (2009).

Geiger (2014) in his survey of the "psychological" elements in business cycle theories presents that the role of confidence could be also amplified by social interactions. "However, both in old theories of the business cycle and in newer approaches, there are those which emphasise the influence of actions by individuals or small groups of individuals as a possible impulse initiating a cycle. Furthermore, if social interaction allows ideas and sentiments to spread so quickly among individuals, then understanding the origin of business cycles may sometimes be understanding the how and why of the first initiating action." (Geiger, 2014, p. 495-496) One of such theories was introduced by Akerlof and Yellen (1985), who presented the theoretical concept when the small group of "near rational" agents in the society causes the change of the economic equilibria. Lux (1995) investigated the behavior of heterogeneous traders. In his model, some of the traders did not have the full access to the information and thus built their expectations on the expectations and behavior of the others. He showed, that by the social interaction and the spread of optimism or pessimism among the traders, the price bubbles could appear on the market.

Regarding the spread of the confidence on the individual level, the agent based models seem to be a very useful tool. Westerhoff (2010) simulated, on the agent based model, a spread of optimism and pessimism among firms, the level of confidence in the neighbourhood was one of the aspects codetermining the supply of the firm. In this model, the endogenous business cycle movement appeared. In addition, Westerhoff (2005) proposed a simplified agent based model focusing on the spread of the confidence among consumers. An agent in his model is making decision according to his/her income and the state of confidence of another, randomly chosen, agent. This model consists only of consumers and the government. The simulation of the spread of confidence among consumers also led to the cyclic movement of the economic activity. Westerhoff and Hohnish (2010) further used this model to test the impact of the increased government spending on the aggregate output in the period of contraction in the business cycle, as was proposed by Keynes (1936).

2.4 Consumer confidence in the ACE model

We have decided to work with the confidence in a similar way as Westerhoff (2010). Rather than using aggregate data, we are simulating the spread of confidence on a lattice of agents. By this setting, we can consider and monitor the spread of confidence from a micro level and include the social interaction into the model. We investigate the impact of the confidence on the economic activity from the demand side, focusing on consumers.[3] The confidence of a consumer (an agent in the model) is endogenous and is determined by his/her economic situation and the level of confidence in his/her neighborhood. The spread of confidence on a lattice could generate also the nonlinear development of an aggregate level of confidence during a cycle.

In this dissertation thesis, we investigate whether the optimistic/pessimistic fluctuations

[3]The similar problem was already discussed by Westerhoff (2005), however, he used a different model. We are investigating the influence of the confidence spread among consumers on the economic activity within the model with different and more sophisticated structure, with different confidence setting and with respect to the social interactions within the agent's neighbourhood.

in consumer confidence could generate a cyclical movement of economic activity. We follow the definition of the business cycle by Robert Lucas, cited also in Hartley, Hoover and Salyer (1998, p.10), who is "defining the business cycle phenomena as the recurrent fluctuations of output about trend and the co-movements among other aggregate time series." As we are working with the simple ACE model, there are no innovations and there is no trend assumed. The turning point of a business cycle is defined as the moment, when the growth rate of income firstly changes from nonnegative numbers to a negative value or from nonpositive to a positive value. Hence, if the waves in consumer confidence lead to a cyclical movement in economic activity and co-movement of other aggregate variables, it could be considered as an endogenous source of business cycle.

The propagation mechanism of the effect of consumer confidence on the economic activity is following. The consumer confidence has a direct impact on his/her consumption demand. According to his/her confidence (i.e. he/she is optimistic/stable/pessimistic) each consumer in the model is willing to increase, keep the same or decrease his/her consumption demand relatively to his/her income from the past period. The longlasting optimism/pessimism of the agent also leads to the adjustment in his/her marginal propensity to consume.[4] The aggregate consumption demand is then influenced by confidence from the bottom up. The spread of the optimism or pessimism among consumers is through their consumption demands entering the aggregate demand and could cause its cyclical movement. This cyclical movement could further destabilize the production plan of a firm. As consumers are paid by the firm for their labor, the income of consumers could vary too. The new economic conditions for consumers are influencing consumers' decision about their future state of confidence. The fluctuations in consumers confidence could, therefore, by the interaction among consumers and firm through different channels, generate the endogenous business cycle movement.

It is also important to mention that the purpose of the dissertation thesis is not to explain the business cycle movement but rather to demonstrate how the waves in consumer confidence (in principle) could contribute to a cyclical movement of an economic activity. The business cycle movement of economic activity could be rather considered as a result of various exogenous shocks combined with a complex economic structure, which could by itself also generate some endogenous cycle movements. However, the proper understanding of individual sources of cyclical movement could enable us to eliminate or at least, partially decrease fluctuations in economic activity.

[4]The exact description of the consumer problem can be found in the theoretical description of already constructed model in Chapter 5.

3 Critical review of current approaches to macroeconomic modelling

We have decided to investigate the endogenous cyclical movement of economic activity in a simplified ACE model. There are more approaches how to track the endogenous movement of economic activity, but in general, it is necessary to build a dynamic model of economic system. Albeit, there is a plenty of criticism to all of these approaches, one approach cannot be generally claimed better than the other. It could be said that one approach is better than the other in a particular situation for tracking a particular problem. For that reason, we would like to describe not only the ACE model, which we are going to use in the thesis, but also the other approaches. These were already shortly mentioned in the introduction, but we would like to describe them now in more detail and make a critical review of their suitability in investigating the spread of the consumer confidence in the macroeconomic model.

3.1 Alternative approaches to macroeconomic modelling

One of the most common approaches in macroeconomics is to use vector autoregressive (VAR) models. The big advantage of this approach is that it could be relatively simple, it is based on real macroeconomic data and in lot of cases sufficient results are achieved. We can investigate macroeconomic relations purely from the empirical point of view, or we can incorporate an economic structure into a model, as it is, for example, in conintegrated vector autoregressive (CVAR) or structural vector autoregressive (SVAR) models. The reactions of endogenous variables from the model on exogenous shocks could be investigated by impulse response functions. The initial relationships among macroeconomic variables could be further estimated also by Granger causality tests. The macroeconomic SVAR model for the Czech Republic was done, for example, by Hančlová (2011).

The studies mentioned in Chapter 3 and focused on the importance of the economic sentiment while predicting the behavior of consumption spending used regression on macroeconomic data. The limitation of this approach is that we investigate on aggregate data and therefore we need time series of the aggregate confidence in society and for the computational reasons we often take an assumption that the relationship among the economic activity and the consumer confidence is linear or partially linear.

Another approach, quite commonly used in these days, is the dynamic stochastic general equilibrium (DSGE) approach. DSGE models are assuming a general equilibrium in economy and investigating a development of macroeconomic variables in the form of deviations from this equilibrium. Models are deeply structured and calibrated by use of real macroeconomic data. They are suitable for modelling various fiscal or monetary policies and widely used mainly in central banks. The DSGE model for European Union was estimated by Smets and Wouters (2003), in the Czech Republic the DSGE models are used in the Czech National Bank (Andrle, Hlédik, Kameník and Vlček, 2009) and in the Ministry of Finance (Štork, Vávra and Závacká, 2009, Štork and Závacká, 2010) for monetary and fiscal projections.

The advantage of DSGE models is that there is a quite deep theoretical structure in them, so they could firstly track various simulations and secondly they could perform better during the turning points of economic activity. The importance of the economic sentiment was already confirmed also in this kind of a model. In the recent years, in the DSGE models researchers are starting to also use some simulation part for economic sentiment in order to improve the rational expectations modelling.

However, these models have also its "tricky questions". Firstly, there is a lot of strong assumptions in these models, such as the existence of an analytically tractable general equilibrium or that the behavior of consumers and firms could be aggregated through the behavior of one or more representative agents. Secondly, for model calibration it is necessary to determine the equilibrium values of all endogenous model variables.

Alhough the DSGE models are well appreciated and very much in use, in the last years, especially after their general fail to predict the last global crisis, there is a growing debate about their qualities for macroeconomic modelling. The usual critique of DSGE model is that "They are based on unappealing assumptions. Not just simplifying assumptions, as any model must, but assumptions profoundly at odds with what we know about consumers and firms." (Blanchard, 2016, p.1). Stiglitz and Gallegati (2011) see the use of representative agent in DSGE models as missleading. The strong negative critique od DSGE models was presented, together with the rebellious notes to recent trends in macroeconomic modelling, by Paul Romer. He stated for example that "Macroeconomists got comfortable with the idea that fluctuations in macroeconomic aggregates are caused by imaginary shocks, instead of actions that people take,..." (Romer, 2016, p. 4). He further explains it on an example: "Suppose an economist thought that traffic congestion is a metaphor for macro fluctuations or a literal cause of such fluctuations. The obvious way to proceed would be to recognize that drivers make decisions about when to drive and how to drive. From the interaction of these decisions, seemingly random aggregate fluctuations in traffic throughput will emerge. This is a sensible way to think about a fluctuation. It is totally antithetical to an approach that assumes the existence of imaginary traffic shocks that no person does anything to cause." (Romer, 2016, p.5). The use of external shock is a very common instrument in DSGE modelling, while evaluating the quality of the DSGE model and constructing the stress model scenarios.

The weak point of DSGE models is their calibration. Romer (2016, p.6) points out that "...when the number of variables in a model increases, the identification problem gets much worse. In practise, this means that the econometrician has more flexibility in determining the results that emerge when she estimates the model." Further, he impeaches the use of prior estimations in DSGE models: " The prior specified for one parameter can have a decisive influence on the results for others. This means that the econometrician can search for priors on seemingly unimportant parameters to find ones that yield the expected result for the parameters of interest." (Romer, 2016, p.7). The calibration of DSGE models and use of priors was also critized by Blanchard (2016, p.2): "Their standard method of estimation, which is a mix of calibration and Bayesian estimation, is unconvincing.". We can firmly accept that calibration of macroeconomic models is always a challenge, because the availability of data is limited, the data are measured in variable economic environment and any macroeconomic model is always based on some simplifying assumptions. Thus, the influence of calibration of macroeconomic model should be always supported by the sensitivity analysis and the check of results' robustness.

The tough critique of DSGE models, however, does not mean that they should be rejected. Even Blanchard (2016) explains, that the weak points of DSGE models could be improved and the use of DSGE models could be beneficial. He explains their position in macroeconomics: "So, to return to the initial question: I suspect that even DSGE modelers will agree that current DSGE models are flawed. But DSGE models can fulfill an important need in macroeconomics, that of offering a core structure around which to build and organize discussions. To do that, however, they have to build more on the rest of macroeconomics and agree to share the scene with other types of general equilibrium models." (Blanchard, 2016, p.4).

In the last years, thanks to the technological development, the new ACE approach has been considered. This approach is investigating macroeconomy from the bottom up, e.g. the macroeconomic features are emerging from the simulations on the micro level[5]. This approach is supported, for example, by Stiglitz and Gallegati (2011). The big advantage of this approach is that it can be used for numerous heterogeneous agents and therefore a lot of assumptions, which are used in DSGE models, could be relaxed. Further, we are no more limited to observe and evaluate economy on the aggregated measurable macroeconomic variables but we can also look into its structure, observe its development, the rate of heterogeneity and the sensitivity of the structure of agents on various settings. Except ACE models there are no other macroeconomic models which are capable to replicate the structure of society. The big disadvantage of this approach is that it is very difficult to fit these models to real data. However, this approach is still quite new and thus, we can believe that with the time, this problem could be solved or at least reduced.

Considering all the features of the methods mentioned above, the ACE approach seems to be an optimal choice for modelling the spread of consumer confidence. The consumer confidence can be simulated already on the micro level, allowing for the interactions among consumers and also for their heterogeneity, for example, in incomes. The cyclical behavior of economic activity further emerges from these interactions on the micro level. As this approach is used in this dissertation thesis, a more sophisticated description follows.

[5]DSGE models are also built on microeconomic principles, however the macroeconomic relations are firstly derived from these principles and the simulation is done on the macro level (the "top down" approach).

3.2 Multiagent model

A vast amount of literature on ACE modelling could be found at the web pages of Leigh Tesfatsion http://www2.econ.iastate.edu/tesfatsi/ace.htm. According to Borrill and Tesfatsion (2010, p.3) "Social systems consist of heterogeneous communicating entities in an evolving network of relationships." In Agent-Based modelling (ABM), "systems are modeled as collections of autonomous interacting entities ("agents") with encapsulated functionality that operate within a computational word" (Borrill and Tesfatsion, 2010, p.4). As the modelling of complex systems is provided from the bottom up, from the behavior of individual agents and their interactions, the main patterns, structure or behavior of these complex systems are emerging from these interactions. This is the main feature of an agent-based model. Further, we present a short description of agent-based modelling in the way it was introduced by Macal and North (2010).

According to Macal and North (2010) "A typical agent-based model has three elements:

1. A set of *agents*, their attributes and behaviors.

2. A set of agent *relationships* and methods of interaction: An underlying topology of connectedness defines how and with whom agents interact.

3. The agent's *environment*: Agents interact with their environment in addition to other agents."

Hence, it is necessary to define and program[6] this structure to be able to run the simulations of agents' behavior and interactions. This is often done, according to Macal and North (2010, p.152) "in time-stepped, activity-based, or discrete-event simulation structure."

3.2.1 Agents

Macal and North (2010, p.153) claim that an agent should have certain characteristics:

- "An agent is a self-contained, modular, and uniquely identifiable individual."

- "An agent is autonomous and self-directed." An agent behaves independently, according to predefined simple rules, with respect to a state of environment and information obtained by interactions.

- "An agent has a state that varies over time." This state should represent the current state of an agent and could be expressed as a set of attributes. The state of all agents together with the state of environment express the state of agent-based model.

- "An agent is social having dynamic interactions with other agents that influence its behavior."

[6]There is an user-friendly program for constructing agent-based models NetLogo (https://ccl.northwestern.edu/netlogo). Another way that could be to used is a programming environment (Matlab, R, C++,..) and program the model.

Macal and North (2010, p.153) further note that aside these essential characteristics, the agents may have additional characteristics:

- "An agent may be adaptive, for example, by having rules or more abstract mechanisms that modify its behaviors." This characteristic could be used to incorporate learning into the model.
- "An agent may be goal-directed, having goals to achieve (not necessary objectives to maximize) with respect to its behaviors."
- "An agent may be heterogeneous."

Following Macal and North (2010, p.154) the agent is associated with attributes and methods that operate on the agent. Attributes could be stable (for example the unique identificator of the agent) or dynamic (for example agent decisions) during simulations. Methods operating over agents could be understood as predefined rules or more abstract representations, which define the behavior of agent according to his/her state, the state of other agents and the state of environment. The definition of these methods should be supported by a proper theoretical background.

3.2.2 Relationships and interactions

As Macal and North (2010, p.154) explain "the two primary issues of modelling agent interactions are specifying who is, or could be, connected to who, and the mechanisms of the dynamics of the interactions." In general, each agent interacts just with some group of other agents, called neighbors. These neighbors provide local information to an agent. Macal and North (2010) are further explaining that there is no central authority in the system, which would spread the local information to all agents. As each agent behaves also according to local information, the whole system is decentralized. The development of the global environment is thus, emerging from interactions among agents.

However, the opinion that only local information is available to agents should be considered in macroeconomic agent-based models. Firstly, in economics there are already agent-based models where agents operate with some global information too. For example, in Westerhoff (2010) the probabilistic distribution determining the firm’s confidence is also a function of the aggregate demand for consumption, which is global information. In Delli Gatti et al. (2011) the agents (firms) know the equilibrium price in economy from the last period.

Secondly, the global information could serve to inform agents about variable state of their environment. Agents are not only parts of their local neighborhood but they are also parts of the whole economy. As well as the macroeconomy is emerging from the microeconomy, the state of macroeconomy is codetermining the state of environment of an agent, hence backwards influencing microeconomy. Even in the most simple models, when there are no fiscal or monetary authorities, there are, for example, some "rules of the game" defined, which is global information known by all agents. Further, in most sophisticated models, focused on fiscal or monetary simulations, there exist a central fiscal or monetary authority which actively changes the "rules of the game". This is again global information about the change of environment distributed to all agents [7].

Thirdly, nowadays there is also global information about the state of economy available to agents through various information channels (newspaper, media, internet, social networks)[8]. There is no need of a central authority to distribute the information. As the information is widely and almost freely available, each agent can search for it and obtain it. Actually, there is even no need to assume that each agent searches for the information. If the information is spread to vast majority of agents, it could be already known in local neighborhood of each agent. In this way, even if the agent is "rationally ignoring" the global information (e.g. searching for global information is for him/her more costly than relying just on local information), he/she could obtain this global information from his/her neighbourhood. Unlike the biological systems, the economic systems nowadays dispose with these progressive information channels which could provide the spread of global information. Thus, even if in agent-based models from other scientific fields only the local information to agents is assumed, in the economic field the role of global information should be considered.

Lastly, we should think about the reason why only the local information was accepted. The main principle of agent-based models in macroeconomics is that they are decentralized and the macroeconomic features are emerging from the interactions on microeconomic level. This main feature of agent-based models has to be kept. Hence, the global information in the model could only play a role to inform agents about the state of economy, as an additional information about their state of environment, but it cannot directly determine the variables on the macroeconomic level. The state of macroeconomy must emerge from the bottom. The role of global impact in this way is also in line with Hayek (1973, p.41), who states: "Since we can know at most the rules observed by the elements of various kinds of which the structures are made up, but not all the individual elements and never all the particular circumstances in which each of them is placed, our knowledge will be restricted to the general character of society of human beings, we may be in a position to alter at least some of the rules of conduct which the elements obey, we shall thereby be able to influence only the general character and not the detail of the resulting order."

"How agents are connected to each other is generally termed an agent-based model's topology or connectedness. Typical topologies include spatial grid of network of nodes (agents) and links (relationships)." (Macal and North, 2010, p.154). These topologies determine how the information will be spread around the whole system. Macal and North (2010) note that the agents could be connected either geographically or through some social network. In addition, agents

[7]The example of this could be the change of personal income tax, which is done by the fiscal authority and immediately followed by all working agents.

[8]For example, the Czech National Bank recently informed public about the end of exchange rate interventions through the media.

could be connected through various topologies. Topologies could be stable or dynamic during simulations. In case of dynamic simulations, the links but also the nodes could be moving.

3.2.3 Environment

The agent-based models allow to define different environment conditions to agents across the topology. Specially in dynamic topologies the environment conditions could be the important source of agents' movement.

The agent-based model has a wide range of applicability. As it is capable to model system development on the basis of interactions among individual agents, it is used across various scientific disciplines. Just to mention some examples, presented also by Macal and North (2010), it is used in biology to track the spread of bacteria, in ecology to track the movement of predators, in epidemic and pandemic models, to investigate the social instability or collective behavior of people in crowds and in economics, for example, to analyze financial markets or labor market.

In macroeconomics, only few agent-based models of the whole economy have been constructed up to date. The massive ACE model EURACE for the economy of the European Union was built by Deissenberg, Van der Hoog and Dawid (2008). The smaller and very interesting ACE model was presented by Delli Gatti, Desiderio, Gaffeo, Cirillo and Gallegati (2011). Another ACE models were constructed, for example, by Dosi, Fagiolo and Roventini (2006, 2010), Ciarli, Lorentz, Savona and Valente (2010) or Westerhoff (2010).

3.3 Calibration and validation of the model

The ACE models have to be calibrated and validated. By the calibration process we are searching for the optimal values of parameters used in the model. As ACE models are based on microeconomic structures, their calibration should be ideally done on microeconomic data. The general problem is now to obtain these microeconomic data. The calibration is directly related to the validation process, when we are trying to estimate how well the model represents the real economy. The common way for validation of models is to compare the model results with the stylized facts known about the observed variables. In macroeconomic models, the usual comparison is done for Phillips curve, Okuns law, distribution of incomes, etc. Fagiolo, Dosi and Gabriele (2004) constructed an ACE model oriented on the labor market and by simulations showed that the model is robustly reproducing the Okun, Beveridge and wage curves. The validation for stylized facts was also done, for example, by Delli Gatti et al. (2011). Another possible instrument for validation is the comparison of the model results, usually the mean values, standard deviation or distribution of simulated variables, with statistical values estimated from their counterparts in real data sets. The calibration and validation of the model is usually done simultaneously (e.g. during the calibration the model is also validated, if the validation is not succesfull, the model is recalibrated anew).

In general, Windrum et al. (2007) introduced three of the most influential approaches which are used for the empirical validation of ACE models - the indirect calibration approach, the Werker-Brenner approach and the history-friendly approach.

3.3.1 The indirect calibration approach

By using the indirect calibration of the ACE model, we are proceeding backwards. Firstly, we validate the model and then, based on the results from the validation, we are calibrating the model. Windrum et al. (2007, p.8) describe this approach in four steps:

1. "In the first step, the modeler identifies a set of stylized facts that s(h)e is interested in reproducing and/or explaining with the model."

2. "In the second step, along with the prescriptions of the empirical calibration procedure, the researcher builds the model in a way that keeps the microeconomic description as close as possible to empirical and experimental evidence about microeconomic behavior and interactions."

3. "In the third step, the empirical evidence on stylized facts is used to restrict the space of parameters, and the initial conditions if the model turns out to be non-ergodic."

4. "In the fourth and final step, the researcher should deepen his/her understanding of the causal mechanisms that underlie the stylized facts being studied and/or explore the emergence of fresh stylized facts (i.e. statistical regularities that are different to the stylized facts of interest) which the model can validate ex post."

By using the indirect calibration the researcher should put more intention into the choice of stylized facts to be replicated. Some stylized facts could be validated without putting any strong restrictions on the parameter space.

3.3.2 The Werker-Brenner approach

In the Werner-Brenner approach we firstly calibrate the model, leaving wide ranges for parameters for which we have less information. Then, during the validation of these models, we are restricting these ranges. This approach is explained by Windrum et al. (2007, p.9) in three steps:

1. "Step 1 uses existing empirical knowledge to calibrate initial conditions and the ranges of model parameters."

2. "Step 2 involves empirical validation of the outputs for each of the model specifications derived from Step 1."

3. "Step 3 involves a further round of calibration. This uses the surviving set of models and, where helpful, recourse to expert testimony from historians."

3.3.3 The history-friendly approach

A history-friendly approach was developed mainly for the ACE models with the focus on industry. We do not distinguish among particular steps in this method. The main idea of this approach is to use historical case studies from industry and use the data from this study not only in validation, but also in constructing the model, defining model variables, agent behavior and its environment, model parameters and also initial conditions. The model is built up according to these data and later again validated on these data. As Windrum et al. (2007, p.11) describe "The authors of history-friendly approach suggest that, through a process of backward induction one can arrive at the correct set of structural assumptions, parameter settings, and initial conditions." As this approach is based on the empirical data from chosen industry, it should be used for micro dynamics.

However, the calibration and validation of ACE models is still in the process of development. As Windrum et al. (2007, p. 13) point out, there are some unresolved issues left. One of these questions is, for example, how to construct the ACE model. One possibility is to start with the simplest one and then extend it ("KISS strategy: "Keep it simple, stupid!"", Windrum et al., 2007, p. 13). Another option is then to do it the other way round, start with the most descriptive model and simplify it ("KIDS strategy: "Keep it descriptive, stupid!"", Windrum et al., 2007, p. 13). The third strategy is to use some already constructed model and either extend or simplify it ("TAPAS strategy: "Take a previous model and add something."", Windrum et al., 2007, p. 13).

The other common problem in ACE models is over-parametrization. The model could be defined with too many degrees of freedom, reproducing practically any possible solution. Hence, the reduction of possible solutions should be done through the calibration and validation. As we are calibrating and validating models on the basis of empirical data sets, we should also care about the quality of the data. According to Windrum et al. (2007) only high quality data should be used.

4 The baseline ACE model

The baseline version of an ACE model was programmed in software R[9]. The first version of this model was described and shortly presented in Závacká (2016), simulations of both models already confirmed the endogenous cyclical movement of economic activity generated by changes in consumer confidence. Aside the main goal of the thesis, the baseline model was already slightly extended and used also for the evaluation of monetary policy simulations in Závacká (2015a). The list of all model variables could be found in Appendix A.1, the list of model equations is in Appendix A.2.

The first baseline model was constructed according to the TAPAS strategy ("Take a previous model and add something.", Windrum et al., 2007, p. 13). The baseline model consists of agents - consumers, who are heterogeneous only in their consumer confidence and hence, consumption spending. For simplicity we assume a uniform distribution of income in society. As the problem of the spread of waves of optimism/pessimism and its relation to the business cycle movement was already solved by Westerhoff (2010), we have started with a replication of his model. The model by Westerhoff (2010) has three big advantages. Firstly, it is quite simple and therefore could be used as a good initial point for constructing more sophisticated structures. Secondly, there is already the spread of waves of confidence defined on the micro level. Thirdly, as the model deals with a similar topic, we can also use this model for calibration of some parameter values. Because we are investigating the confidence from the perspective of consumer, numerous changes in the model were necessary. Thus, we have reduced the model of Westerhoff (2010) to the simulation of confidence and the general structure (the concept of two differnet kinds of steps) and redefined the essential relations. Further, we have followed the KISS strategy ("Keep it simple, stupid!", Windrum et al., 2007, p. 13) and built the model step by step into its baseline version.

Westerhoff (2010) concentrates, in his model, on the spread of optimism and pessimism among firms leading to the cyclical behavior of economic activity. We use the definition of the spread of waves of optimism/pessimism in line with Westerhoff (2010), however with strong modifications. Firstly, we relate the waves of confidence with consumers (agents), therefore not with the aggregate supply, but directly with aggregate demand. Secondly, we defined the states of confidence in a different way. Because the confidence in the model is connected with the consumers and influencing aggregate demand, while the confidence in the model of Westerhoff (2010) is connected with firms and the aggregate supply, the adjustment of the confidence definition is needed. Finally, we introduce the third possible state of consumer's confidence - the stable state.[10] In addition, we have introduced consumers in the model, aggregated the production sector under one firm and redefined the behavior of the firm. All other changes in comparison to the model of Westerhoff (2010) are mainly resulting from this different setting.

[9]The code of the baseline model can be found in Appenidx A.4 and in the attached CD.

[10]The motivation for a redefinition of the confidence and adding stable state into the model is explained in 4.1 within the explanation of the confidence spread.

The simulations of this model generate the cyclical movement of economic activity too.

The simple ACE model is constructed as a miniaturized model of economy, presented on the lattice of M interconnected agents (consumers) and one production unit - firm. The simulation of behavior of this system runs in two types of steps - macrosteps t and microsteps τ. The global situation of economy traced by the main macroeconomic variables is evaluated during macrosteps. Between each two macrosteps t and $t+1$ there are T microsteps, during which the confidence in society is simulated. In each microstep τ one agent is randomly chosen from the lattice. This agent, according to the global conditions (known from the last macrostep t) and the consumer confidence from his/her neighborhood decides to be either optimist, pessimist or a stable agent. After T microsteps the new state of aggregate confidence together with the new state of economy is evaluated (macrostep $t+1$). As we are going to describe the simulation part of the confidence between the macrosteps t and $t+1$ and then the evaluation of the new state of macroeconomy in macrostep $t+1$, the majority of model equations defining the new states of macroeconomic variables are expressed with respect to the macrostep $t+1$. We have run the simulations for TT macrosteps.

4.1 The spread of economic confidence

As we already mentioned, during the microsteps, the agents form their state of confidence. Westerhoff (2010) distinguished only among optimistic and pessimistic state of confidence. However, the confidence was connected with the intention of the firm either to increase or decrease its production. If we imagine the perfect competitive environment on the market and profit-maximizing strategy of firms, only two states of confidence seem to be sufficient. As it is in Westerhoff (2010), the optimistic firm expects the increase of aggregate demand and hence is willing to increase its individual supply, and vice versa, the pessimistic firm expects the decrease in aggregate demand and hence is willing to decrease its supply.

In case of consumer, the situation is slightly different. The consumer could be optimistic in the sense that he/she is expecting the growth of his/her future stream of incomes, however, he/she could be not necessarily motivated to increase the consumption spending proportionally to his/her last income. According to Keynes's (1936) basic psychological law consumers are increasing their consumption with their increasing income, however not by the same rate (e.g. their marginal propensity to consume is variable). The difference in this rate is also supported by Deaton (1989) who introduced the idea of "buffer stock" savings. According to Deaton (1989), if a consumer´s income is rising, the consumer will firstly prefer to accumulate some savings as a protection for the possible time of need (called "buffer stock") than immediately spend all the increased income on consumption. The same idea could be applied in the case of pessimism. The consumer could be rather pessimistic about his/her future stream of incomes but it does not imply that he/she will always decrease his/her consumption spending proportionally to his/her income (e.g. the marginal propensity to consume is variable). According to Pollin (1988), if the income of consumer is decreasing, the consumer can be motivated to borrow financial resources to maintain household living standards. The positive or negative expectations about income need not directly lead to an increase or decrease in individual consumption spending proportionally to his/her income.

For that reason, we have decided to define the consumer confidence with respect to his/her intention to increase, stabilize or decrease his/her individual consumption spending and introduce the third state of confidence - stability. Thus, in the model, we distinguish among three possible states of confidence: optimism, pessimism, and stability. Optimist is understood as a consumer who wants to increase his/her consumption spending in relation to his/her last income[11]. Pessimist is a consumer who wants to decrease his/her consumption spending in relation to his/her last income. The stable agent is an agent who does not want to change the level of his/her consumption spending in any direction (in relation to his/her last income). The confidence of i-th consumer in the macrostep t and microstep τ is represented by the variable $Mood^i_{t\tau}$

$$Mood^i_{t\tau} = \begin{cases} -1 & \text{consumer is a pessimist,} \\ 0 & \text{consumer is a stable agent,} \\ 1 & \text{consumer is an optimist.} \end{cases} \tag{4.1}$$

Westerhoff (2010) simulated the confidence of the production firm according to probability distribution with respect to two factors - the change in aggregate demand and the influence from the producer's neighborhood. Instead of probabilistic distribution we use weights for initial factors (this was used for generating consumption spending by consumers, for example, by Cahlík (2006)). The agent's confidence is affected by two factors. Firstly, in line with the definition of consumer confidence indicator by the European Commission (2016), we assume that the change in consumer's confidence is highly influenced by his/her expectations about future incomes. These expectations are supposed to change with the change in consumer's income during macrosteps. The expectations of an agent i about his/her future incomes ($Expincome^i_t$) in macrostep t are defined as

$$Expincome^i_t = sign(Y^i_t - Y^i_{t-1}) \tag{4.2}$$

(e.g. positive in case of the income growth, negative in case of the income fall and 0 in case the agent's income is equal to his/her income in the previous period), where Y^i_t is an income of the agent i in macrostep t.

The second factor is assumed to be, in line with Westerhoff (2010), the influence from the agent's local environment. The more optimists are in the agent's neighborhood, the more likely is the agent becoming an optimist, the more stable agents are around agent, the more likely he/she becames stable too and the same analogy holds for pessimism. In this point, the question

[11]The exact relationship between the consumer's confidence and his/her demand for consumption spending will be specified in Chapter 5.1.2 while introducing the consumer behavior in the model.

is: "What is the neighborhood of an agent and how to define the structure of the net?" We have decided to follow the simple structure used by Westerhoff (2010). Thus, we are using the net in the form of an anuloid, where each agent has exactly four neighbors (the one up, down and on the right and left side). The influence from the agent's neighborhood is expressed as an average mood in the agent's neighborhood.

To define the new state of confidence of an agent, we firstly calculate the weighted average of both influences (weighted by the parameter of sensitivity on income α^y) on the confidence of an agent i in the macrostep t microstep τ as $Influence^i_{t\tau}$

$$Influence^i_{t\tau} = \alpha^y \cdot Expincome^i_t + (1 - \alpha^y) \cdot \frac{1}{4} \sum_{j \in N^i} Mood^j_{t\tau}, \tag{4.3}$$

where N^i is a set of agents in the neighbourhood of agent i[12]. The variable $Influence^i_{t\tau}$ is in its minimum -1 when the expectations of future income of an agent are negative and is surrounded by pessimists only. The maximal value is achieved for an agent with positive income expectations, surrounded by optimists only. For the simplicity, we divide this interval $[-1, 1]$ into three equal parts and define the new state of confidence $Mood^i_{t\tau}$ of an agent i in macrostep t and microstep τ as

$$Mood^i_{t\tau} = \begin{cases} -1 & Influence^i_{t\tau} \leq -\frac{1}{3}, \\ 0 & -\frac{1}{3} < Influence^i_{t\tau} \leq \frac{1}{3}, \\ 1 & \frac{1}{3} < Influence^i_{t\tau}. \end{cases} \tag{4.4}$$

During the model simulations, we have more possibilities to observe the consumer confidence in the society. Thanks to the construction of the ACE model, we are able to observe the spread of confidence directly on the lattice, from the micro level. We can also measure the aggregate level of confidence in the society (on the macro level) to compare it with the other macroeconomic variables. The changes in consumer confidence are simulated during microsteps, thus the mood of each consumer is always expressed in certain macrostep and the certain microstep. To compare it with macroeconomic variables observed in the aggregated form during macrosteps only, we have to define also the mood of consumers in each macrostep only and in the aggregated form.

Because the model is dynamic, the aggregate variables are defined on their past values from previous macrosteps and according to the results from simulation of confidence spread. Thus, we define the model variables for the macrostep $t + 1$ on the basis of their states in the macrostep t and sooner and the confidence spread's simulation results driven between macrostep t and $t + 1$. The definition of model variables for macrostep $t + 1$ is also in line with the definitions used in the code of the programme. While introducing the variables in the text, the appropriate index for the macrostep will be used.

Let us firstly assign the confidence of each i-th consumer in macrostep $t + 1$ expressed

[12]As we are working with the lattice in the form of torus, each agent has exactly four neighbours - one above him/her, one bellow him/her and one from each side of him/her in the lattice.

by $Mood^i_{t+1}$ as the state of confidence after the microsteps' simulation after macrostep t, e.g.

$$Mood^i_{t+1} = Mood^i_{t,TT}. \tag{4.5}$$

Further, let us define the indicator of consumer confidence in the society in the macrostep $t+1$ as $CONF_{t+1}$

$$CONF_{t+1} = \sum_{i=1}^{M} Mood^i_{t+1}. \tag{4.6}$$

This indicator has a maximum value M when all agents are optimists and a minimum value $-M$ when all agents are pessimists. According to the definition of confidence (4.1) we can compute the total number of optimists O_{t+1}, stable agents ST_{t+1} and pessimists P_{t+1} in each macrostep $t+1$.

$$O_{t+1} = |\{i : Mood^i_{t+1} = 1\}|. \tag{4.7}$$

$$P_{t+1} = |\{i : Mood^i_{t+1} = -1\}|. \tag{4.8}$$

$$ST_{t+1} = |\{i : Mood^i_{t+1} = 0\}|. \tag{4.9}$$

Thus, the indicator of consumer confidence in the society could be also expressed as

$$CONF_{t+1} = O_{t+1} - P_{t+1}. \tag{4.10}$$

It is not trivial to separate the optimistic and pessimistic wave of confidence. Should we consider the decrease of number of optimists in the society, after its peak, the second phase of the optimistic wave, being represented by a return to some stable state of confidence in the economy, or should we rather consider it a beginning of the pessimistic wave? As the waves usually melt one into the other, we have decided to define, in the model, the waves of optimism and pessimism in consumer confidence as positive or negative deviations from the state, when the confidence in the society is balanced, e.g. when $CONF_t = 0$. The aggregate confidence in the society $CONF_t$ is according to the (4.6) a sum of the confidence across all agents in the net, when the confidence ($Mood^i_t$) of an optimist is equal to 1, the confidence ($Mood^i_t$) of an pessimist equal to -1 and confidence of an stable agent equal to 0 (follows from the definition (4.4) and (4.5)). Thus, this state, when the aggregate confidence in the society is balanced, e.g. $CONF_t = 0$, happens when there is the same amount of optimists and pessimists in the society, no matter how many stable agents are there. The deviation from this state means that there are more optimists than pessimists in the society (in wave of optimism) or more pessimists than optimists (the wave of pessimism). Of course, because of the confidence simulation, the exact value 0 for $CONF_t$ does not always have to be achieved. During the simulation, there could be more optimists than pessimists in the society in macrostep t and in the next macrostep $t+1$ the situation could be oposite, e.g. crossing the blanced state within the simulation between two macrosteps. As we are going to analyze the impact of the waves of optimism and pessimism on the aggegate demand within our dissertation thesis, we have to use an exact definition for the waves. Thus, we define the wave of optimism and pessimism in the following way.

The wave of optimism in confidence

Let $I = \{t_l, t_{l+1}, \ldots, t_m\}$ is a set of macrosteps where $CONF_{t_l} > 0$, $CONF_{t_j} \geq 0$ for all $l < j \leq m$ and $CONF_{t_{l-1}} \leq 0$ and $CONF_{t_{m+1}} < 0$ hold for $l > 0$ and $m < TT$, respectively. We call such a set I as a wave of optimism in confidence.

The wave of pessimism in confidence

Let $I = \{t_l, t_{l+1}, \ldots, t_m\}$ is a set of macrosteps where $CONF_{t_l} < 0$, $CONF_{t_j} \leq 0$ for all $l < j \leq m$ and $CONF_{t_{l-1}} \geq 0$ and $CONF_{t_{m+1}} > 0$ hold for $l > 0$ and $m < TT$, respectively. We call such a set I as a wave of pessimism in confidence.

The graphical presentation of the waves of optimism and pessimism on the development of this confidence indicator is in Figure 4.1.

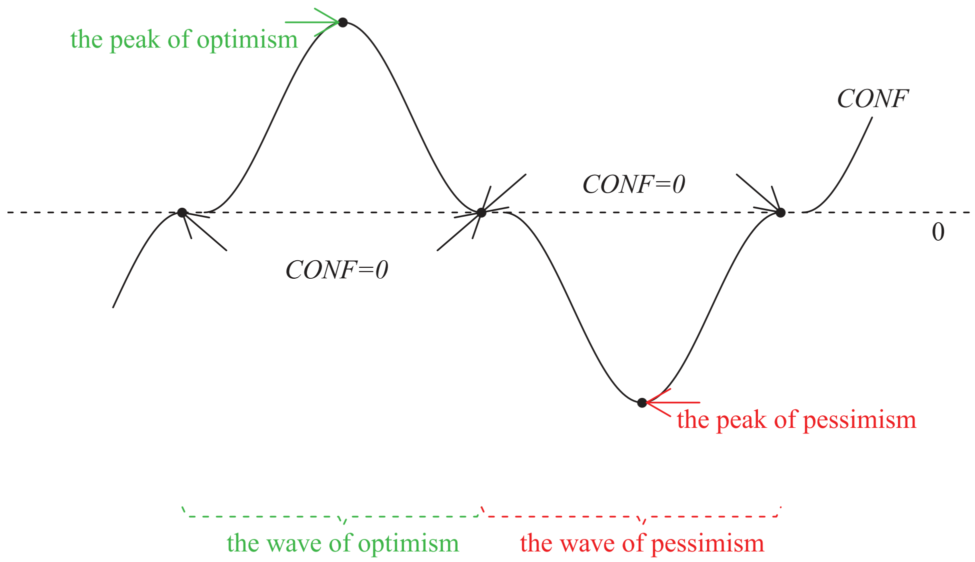

Figure 4.1: The waves of confidence.

4.2 The macroeconomic part of the model

The model was constructed for the purpose of observing the impact of consumer confidence on economic activity, measured by the aggregate income. As the confidence is simulated on a micro level, model consists of M agents, which are heterogeneous in confidence. The production unit is represented by one firm. For the simplicity, we consider the closed economy with no monetary authority, no capital market, constant prices (as Westerhoff (2010) did) and zero real interest rate.[13] Without any loss of generality, we can directly normalize the price of goods to 1. In the baseline model there is no fiscal authority. The scheme of the baseline model with the description of its main macroeconomic structure is presented in Figure 4.2. The color of the agents express their confidence (green for optimism, black for stable mood, red for pessimism).

Concentrating on the pure impact of consumer confidence on an economic activity enables us to evaluate this impact without any side effects. Moreover, the goal of the thesis is not to develop the business cycle theory but rather to present how the waves of optimism/pessimism in consumer confidence can contribute to the cyclical movement of economic activity. The complex analysis of the impact of waves of optimism/pessimism in consumer confidence on economic activity within a more sophisticated model could be a starting point for the future research in this field.

[13]The constat price level is a common assumptions in many demand oriented models, for example in IS-LM models.

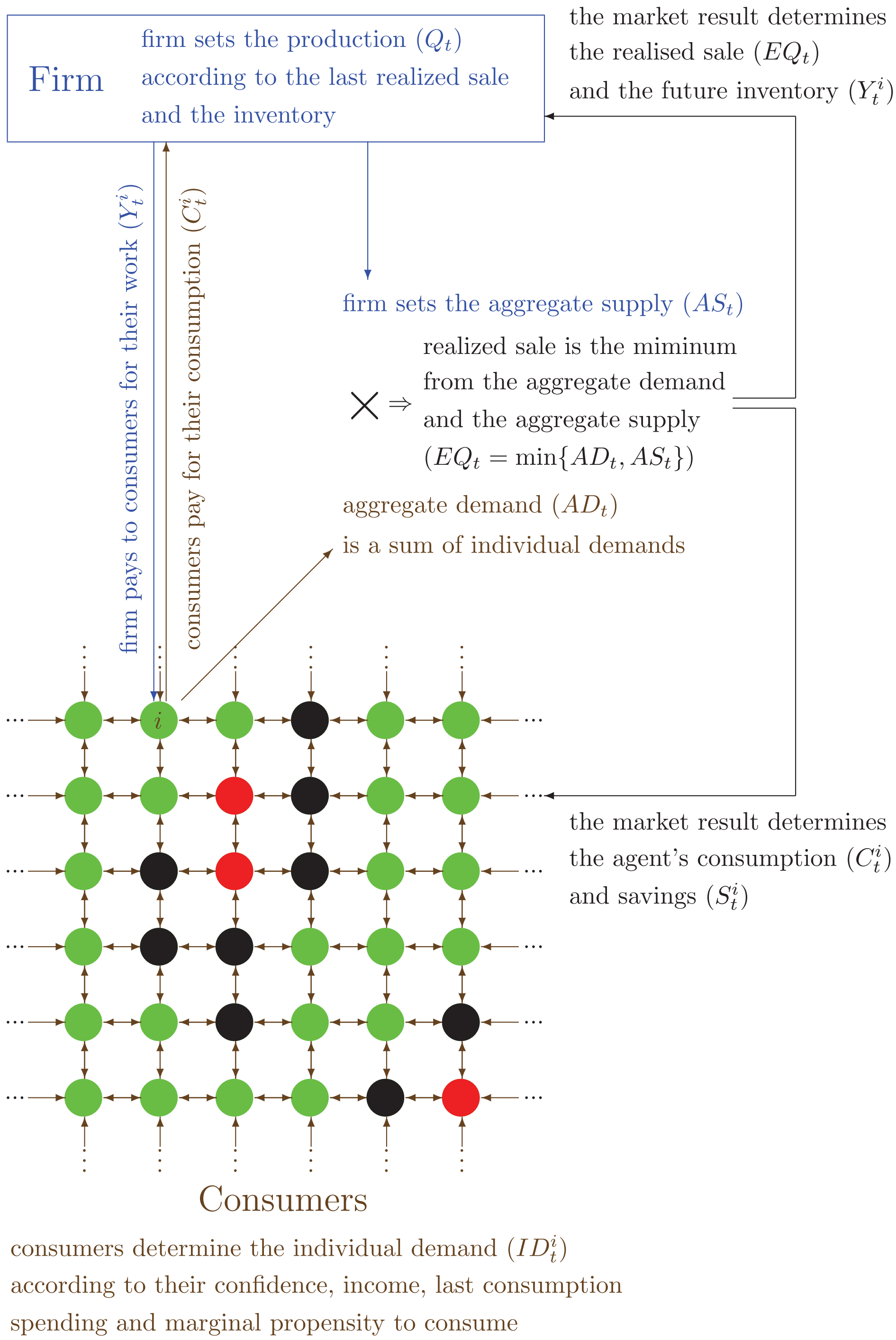

Figure 4.2: The scheme of the baseline model.

4.2.1 Consumers

In the baseline model the aggregate income is uniformly distributed among agents. Thus, the individual income of every consumer i in the time $t+1$ is

$$Y_{t+1}^{i} = \frac{1}{M} Y_{t+1} \tag{4.11}$$

Consumers divide it between consumption spending and savings. The decision about consumption spending is based on the Rational Expectation Permanent Income Hypothesis (REPIH, Hall, 1978). According to this hypothesis, a consumer makes a decision about his/her consumption spending, not according to the immediate, but rather permanent income (Friedman, 1957), with expectations about future stream of permanent incomes being based on rational expectations.

In line with Carroll, Fuhrer and Wilcox (1994) we use the consumer confidence as a proxy for modelling the rational expectations about the future stream of incomes. Carroll, Fuhrer and Wilcox (1994) confirmed on macroeconomic data that consumer confidence does not serve only for predicting the future stream of incomes but rather contains additional information which could not be obtained from other measurable macroeconomic variables. Also in this model, we do not work with the confidence only in relation to expected future incomes. The consumer confidence in the model serves as a factor of switching the marginal propensity to consume as well.

According to Keynes (1936), the marginal propensity to consume is influenced by objective and subjective factors. Aside the objective factors such as the change in the interest rate, the change in the wage unit or change in fiscal policy, which are not applicable to our simplified model, one of the objective factors is the change in the estimation of the relation between immediate and future level of incomes. He concludes that impact of this influence on the society as a whole is rather balanced, however mentions that on the individual level it could be strong. Further, he explains that according to the basic psychological law, people are generally willing to increase their consumption with an increase in their income, however not with the same rate of growth. He emphasizes that this holds mainly in short periods, during the cyclic fluctuations in employment, when the adjustment for the new conditions is slow. According to him, a consumer attempts to maintain his/her living standard and thus is willing to save more during the first periods of increasing income and vice versa, save less during the first periods of decreasing income. In addition, he states that the share of income, which is saved, is also increasing with the increase in real income. This statement is explained by the idea that during the periods of low income, consumers are motivated to satisfy their basic needs, however with the increase in their income this need is already satisfied and the motivation for accumulation is growing.

Among subjective reasons, which should have, according to him, an influence on the marginal propensity to consume, is to build the cash allowance for unexpectable circumstances, ensure the future relationship between consumer income and his/her needs or his/her family needs, different to the actual state (this is meant as building an accumulation for future financial support in education, old age etc.), the possibility to increase the lifelong consumption spending during time, increasing financial freedom for undertaking unclear or risky projects and investments, building a bequest and satisfy the stinginess. However, he further states that the impact of these subjective factors could be offsetted by the fluctuations in the interest rate.

In his work, he further focuses on the relation between the consumption spending and the income on the aggregate level. He states that on this level, we can take the marginal propensity to consume as stable. However, in this agent based model, the influence of the marginal propensity to consume is integrated to the determination of consumption spending on the individual level. Thus, we take into the consideration the basic psychological law of Keynes (1936) and assume that the adjustment of the agents' consumption spending to the changes in his/her personal income is during the cyclical fluctuations in employment, slow. Further, we also follow his idea that the consumption spending is increasing with the increasing income, however not with the same rate of growth. The variability of the marginal propensity to consume could be supported also by Deaton (1989) with his idea of the buffer stock savings. Fereidouni and Tajaddini (2015) presented the suggestion that the high degree of consumer confidence is rather connected with the higher level of investment activity. Taking into account that the utility function is a growing concave function of consumption spending, the marginal propensity to consume cannot be constant and varies during the business cycle.

Following these statements, the marginal propensity to consume in our model, related to the individual consumption spending should vary continuously. We have decided, for the simplicity, to distinguish only among three cases. Firstly, the marginal propensity to consume should decrease in favor of postponed consumption with growing income in time of positive expectations (this is following the Keynes (1936) and the idea of buffer stock savings, Deaton (1989)). Thus, we define the negative change in marginal propensity to consume for consumer, who is already an optimist for a longer time. For the simplicity, we set this "longer time" as last five macrosteps [14]. Secondly, during the period of decreasing income and negative expectations, the marginal propensity to consume should increase to keep the level of consumption on previous periods, even at the expense of decreasing savings (this idea was supported by Keynes (1936) and Pollin (1988)). Thus, we want to decrease the agent's marginal propensity to consume if the agent is a pessimist for a longer time. For the simplicity, we set the adjustment of marginal propensity to consume positive after five succeeding periods when the agent is pessimist. In all other cases, the adjustment of marginal propensity to consume is zero (e.g. there is no change in the marginal propensity to consume). The change in marginal propensity to consume Δmpc^{i}_{t+1} of an agent i in the macrostep $t+1$ is expressed by the consumption sensitivity parameter α^{mpc}

[14]We can also choose a different amount of macrosteps and provide the sensitivity analysis for this.

defined as

$$\Delta mpc^i_{t+1} = \begin{cases} \alpha^{mpc} & Mood^i_{t-3} = Mood^i_{t-2} = Mood^i_{t-1} = Mood^i_t = Mood^i_{t+1} = 1, \\ 0 & Mood^i_{t+1} = 0, \\ -\alpha^{mpc} & Mood^i_{t-3} = Mood^i_{t-2} = Mood^i_{t-1} = Mood^i_t = Mood^i_{t+1} = -1. \end{cases} \tag{4.12}$$

To be able to observe the changes in marginal propensity to consume on the aggregate level, we define the indicator of marginal propensity to consume MPC_{t+1} in macrostep $t+1$ as

$$MPC_{t+1} = \sum_{i=1}^{M} \Delta mpc^i_{t+1}. \tag{4.13}$$

This indicator is in its maximum value ($0.15 \cdot M$, e.g. 240) when all agents are pessimists and prefer to increase consumption spending even for the reduction of their savings. The minimum value of MPS ($-0.15 \cdot M$, e.g. -240) is achieved when all agents are optimists and prefer to increase their share of savings on their immediate income.

Each consumer determines his/her target consumption. According to his/her confidence the consumer would like to increase, keep or decrease the share of consumption spending in his/her individual income. The target consumption is further influenced by the agent's marginal propensity to consume. The target consumption spending $\bar{C}^i_{t+1}$ of agent i in macrostep $t+1$ is defined as

$$\bar{C}^i_{t+1} = \begin{cases} (1 + x + \Delta mpc^i_{t+1})Y^i_{t+1} & \text{optimist,} \\ Y^i_{t+1} & \text{stable agent,} \\ (1 - x + \Delta mpc^i_{t+1})Y^i_{t+1} & \text{pessimist,} \end{cases} \tag{4.14}$$

where x is an extrapolation constant.[15]

According to Abel (1990) we assume that there is a habit in consumer behavior in the form of ratio γ of his/her previous consumption spending. At the same time, we consider the consumer having some positive level of consumption to keep him/her alive and set this minimum level of consumption as C^0. Therefore, the individual demand for consumption spending ID^i_{t+1} of the agent i in macrostep $t+1$ is defined as

$$ID^i_{t+1} = \max\left\{C^0, \gamma C^i_t + (1-\gamma)\bar{C}^i_{t+1}\right\}, \tag{4.15}$$

where C^i_t is consumption spending of the agent i in macrostep t. Summing up for all agents, the aggregate demand for consumption spending AD_{t+1} in macrostep $t+1$ is obtained.

$$AD_{t+1} = \sum_{i=1}^{M} ID^i_{t+1}. \tag{4.16}$$

[15]The change in marginal propensity to consume is from its definition (4.12) zero for a stable agent, hence is not included in the formula.

4.2.2 Firm

The production sector in the model produces only one type of goods and uses a homogeneous producing process. For the simplicity, we assume that there is a competitive environment on the market. In case there are no returns to scale in production we can consider this sector to be represented by one firm.[16] In case there are many homogeneous firms in society, we can assume that this representative firm is profit maximizing and its economic profit is zero. The investment of the firm is considered solely in the form of inventory. There is no depreciation of capital considered in the model.

The firm in macrostep $t+1$ creates the aggregate supply AS_{t+1}, which consists of a production Q_{t+1} in macrostep $t+1$ and an inventory I_{t+1} in macrostep $t+1$, created from the unsold products in time t.

$$AS_{t+1} = Q_{t+1} + I_{t+1}. \tag{4.17}$$

In each macrostep $t+1$, the firm has to decide how much it will produce. This production strategy is connected with the estimation of future demand for its good. According to Fisher et al. (1994), the forecasting errors in such estimation could lead to two types of loss. Firstly, the firm can lose from keeping to much involuntary inventory. The second loss of the firm is connected with lost sales caused by insufficient supply, this type of loss could be, however, hardly estimated. Fisher et al. (1994) emphasize the importance of improving future demand estimations to decrease these type of losses. Kahn and McConnell (2002) point out that firms could be motivated to keep some level of inventory as a "buffer stock" for smoothing production in times of increased volatility in their sales. West (1989) showed, using a simple linear-quadratic model for inventory on the US data, that keeping a plausible inventory-sales ratio could decrease the losses caused by cost shocks. Blinder and Maccini (1991) stated that introducing an inventory into the production function of a firm is important. According to these recommendations the production strategy of the firm in this ACE model is keeping a fixed inventory-sales ratio with respect to the state of inventory.[17] The target aggregate supply in macrostep $t+1$ is set to be a double of sales from last period (EQ_t). At the same time, the production possibility of the firm is limited by the maximum amount of available (existing) workforce, e.g. M agents, and cannot be negative. Thus, the target production $\bar{Q}_{t+1}$ in macrostep $t+1$ is defined as

$$\bar{Q}_{t+1} = \max\left\{0, \min\{a^L M, 2EQ_t - I_{t+1}\}\right\}, \tag{4.18}$$

where a^L is the marginal productivity of labor. In line with Fagiolo, Dosi and Gabriele (2004) we define the production Q_t as a function of labor only,

$$Q_{t+1} = a^L L_{t+1}, \tag{4.19}$$

[16]Using one representative firm for the whole production sector is a common assumption in DSGE models and could be found, for example, in Smets and Wouters (2003), Štork, Vávra and Závacká (2009), Štork and Závacká (2010).

[17]The inventory in the production function was also used, for example, by Riccetti, Russo and Gallegati (2015).

where L_{t+1} is an amount of labor demanded by the firm and provided by all agents. The labor and the aggregate income is uniformly distributed among all agents, thus we are not considering the unemployed agents in the model.[18] However, we can measure the rate of unemployment in the model through the units of labor. We can express the labor utilization by the share of L_{t+1} in M (which corresponds to the amount of labor provided by one agent in macrostep $t+1$). The full employment is considered as a case when $L_{t+1} = M$, e.g. each agent provides exactly one unit of labor. Similarly, we can measure the labor "non-utilization" as $M - L_{t+1}$, this would express the amount of labor units which was not used in production. The share $M - L_{t+1}$ in M could be considered as an approximation of the rate of unemployment.

Because we are considering the competitive environment, the economic profit of the firm is zero. Hence the value of produced goods is equal to its production costs (in this case just payment for the labor is considered). The price of goods is normalized to 1, thus the value of produced goods is equal to the amount of aggregate production Q_{t+1}. The production function includes only the labor, therefore the only production costs are labor costs. The firm then pays out the aggregate value of production in the form of wages to agents.[19] As it is the only income of each agent, the value of production is directly equal to the aggregate income Y_{t+1}

$$Y_{t+1} = Q_{t+1}. \tag{4.20}$$

4.2.3 Market equilibrium

The aggregate demand is confronted with the aggregate supply on the market of goods. The resulting realized sale EQ_{t+1} is then equal to

$$EQ_{t+1} = \min\{AD_{t+1}, AS_{t+1}\}. \tag{4.21}$$

This sale is also equal to realized consumption spending, e.g.

$$EQ_{t+1} = C_{t+1}. \tag{4.22}$$

In case, an aggregate demand is satisfied, all individual demands for consumption spending are satisfied. As the main strategy of the firm is keeping some inventory stock for unexpected fluctuations in the aggregate demand, the aggregate demand should be, in most cases, satisfied. However, in case the fluctuation in the aggregate demand is big and the inventory stock is to small to cover it, the unsatisfied part of the demand is distributed among agents proportionally to their individual demands. The individual consumption spending C^i_{t+1} of an agent i in the macrostep $t+1$ is then

$$C^i_{t+1} = C_{t+1}\frac{ID^i_{t+1}}{AD_{t+1}}. \tag{4.23}$$

[18]The heterogeneous labor market with unemployed agents is in extended version of this model.

[19]The situation is equivalent to the case when considering a positive economic profit, directly uniformly distributed among all agents.

This further determines individual savings S^i_{t+1} and aggregate savings S_{t+1} of consumers

$$S^i_{t+1} = Y^i_{t+1} - C^i_{t+1}, \tag{4.24}$$

$$S_{t+1} = \sum_{i=1}^{M} S^i_{t+1} = Y_{t+1} - C_{t+1}. \tag{4.25}$$

Savings are always just the amount of income obtained in time $t + 1$ which was not used for consumption spending in the same time. The accumulation of savings during the time is expressed by assets. The assets A^i_{t+1} of a consumer i and the aggregate assets of all consumers A_{t+1} in time $t + 1$ are

$$A^i_{t+1} = A^i_t + S^i_{t+1}, \tag{4.26}$$

$$A_{t+1} = \sum_{i=1}^{M} A^i_{t+1} = A_t + S_{t+1}. \tag{4.27}$$

The resulting realized sale further determines a new state of inventory of the firm, I_{t+2}.

$$I_{t+2} = AS_{t+1} - EQ_{t+1}. \tag{4.28}$$

By the equations (4.1)-(4.28) the baseline ACE model is defined. Just for the transparency, these equations imply following identities

$$Y_{t+1} = C_{t+1} + I_{t+1} - I_t, \tag{4.29}$$

$$S_{t+1} = I_{t+1} - I_t. \tag{4.30}$$

In the model we are considering investment of firm only in the form of inventory, hence the change of inventory $I_{t+1} - I_t$ represents an investment in the time $t + 1$.

4.3 Calibration and validation of the model

The calibration of the model was done by an indirect calibration approach. In the first phase of this calibration process the parameter values should be set according to empirical studies and recent knowledge. Because the model was meant to be simple, it relies on rather many restrictive assumptions such as the closed economy, constant price level, no monetary or fiscal authority and no capital market. It is disputable if the calibration according to real data, which do not satisfy these assumptions, could be beneficial[20]. Further, because of these simplifying assumptions,

[20]For instance, in the model there is no growing trend in the aggregate demand assumed. The changes in the consumer's income (e.g. behavior of the aggregate income) participate on his/her decision about confidence, they further determine the aggregate supply and through the other variables influence all model variables. All real data are measured in the economic enviroment, where the aggregate income has a growing trend. Comparing these data would be like comparing two different economic enviroments. Thus, comparison of the relationships rather than the exact data is prefered.

it is even more difficult to find some stylized facts which could be replicated by this model. As the model was constructed on the base of the model of Westerhoff (2010), we have decided to use some parameter values from Westerhoff (2010) and calibrate the model to be in line with his results. This approach can help us not only to set the parameter values but allows us to compare the achieved results with the results of Westerhoff (2010). The other parameter values were used from the other DSGE or ACE macroeconomic models. After the simulations, the model was controlled to satisfy the commonly accepted relations between macroeconomic variables on the aggregate level. According to this validation the model was calibrated backwards. For the parameters of consumer confidence from the simulation on the micro level the analysis of sensitivity was provided.

We have constructed the model of $M(= 1600)$ agents connected through the lattice in the form of torus.[21] Westerhoff (2010) was working with 10000 agents (firms), however Cahlík et al. (2006) modeled the behavior of agents (consumers) on the net of 1000 agents. Thus, we have decided to work with 1600 agents. Each simulation has $TT(= 200)$ macrosteps. Between each two macrosteps $T(= 1600)$ microsteps were driven. Hence, with 1600 agents, each agent during the simulation of confidence within 1600 microsteps considers his/her state of confidence on average once (this frequency of reconsidering the state of confidence is in line with Westerhoff (2010) setting). The weights between the influence of local neighborhood and future income expectation on the consumer confidence was uniformly distributed by the parameter $\alpha^y(= 1)$. The consumption sensitivity parameter for adjustment of the marginal rate of consumption α^{mpc} was set to -0.15. Because we do not have much information about these parameters of confidence on the micro level (α^y and α^{mpc}), the parameters were tested for a wide range of values during the sensitivity analysis. The parameter of consumption smoothing γ is usually set in macroeconomic models around 0.7 - 0.9 (for example in Štork, Vávra and Závacká (2009)). However, we are applying this parameter on the micro level. Thus, we set γ according to a meta-analysis focused on the estimation of this parameter made by Havranek et al. (2016) to 0.55 (the mean value of this parameter with respect to weighted summary statistic on all estimations of this parameter). The parameter a^L equal to 1 was used, for example, in Ciarli et al. (2010). All values of parameters used in the model can be found in Table 4.1. The statistical analysis was made on $TTT = 100$ model simulations.

Because the model is dynamic, we have to set the starting point to run the simulations. We did not want to choose as a starting point an extreme case (full employment[22] or a depression). Thus, we have decided to set the starting point on the level of 6% unemployment (e.g. amount of labor $L_1 = 0.94 \cdot M$). The production in macrostep 1 is equal to the production produced by this amount of labor and the value of this production is according to (4.20) distributed as the income to consumers. The aggregate demand is, for the simplicity, set to the amount

[21]As there are many possibilities how to set the lattice and connections among agents, we have used the simple construction which was employed by Westerhoff (2010).

[22]The full employment is understood as a case when all agents offer one unit of labor, e.g. $L_t = M$, more in Chapter 5.2.2.

of consumers' income. The inventory of the firm is equal to the amount of production to be in line with the definition of a target production (4.18). The amount of assets held by consumers is equal to the amount of inventory held by the firm. The change in the marginal propensity to consume and the income expectations are set to 0 for all agents. The half of the agents are left to be optimists and half of them stable. According to this confidence setting the aggregate demand for the next macrostep 2 is simulated. All other starting values are determined by the model equations. The starting point can be found in Table 4.2.

Parameter	**Description**
$M = 1600$	Number of consumers
$T = 1600$	Number of microsteps
$TT = 200$	Number of macrosteps
$TTT = 100$	Number of macrosteps
$x = 0.1$	Extrapolation parameter
$\alpha^y = 1$	Income sensitivity parameter
$\alpha^{mpc} = -0.15$	Consumption sensitivity parameter
$\gamma = 0.55$	Habit parameter by consumption
$C^0 = 0.6$	Minimal consumption parameter
$a^L = 1$	Labor productivity parameter

Table 4.1: Parameter setting.

$O_1 = 800$	$AD_1 = 1504$	$C_1 = 1504$	$L_1 = 1504$	$I_1 = 1504$
$ST_1 = 800$	$AS_1 = 3008$	$S_1 = 0$	$Q_1 = 1504$	$Expincome^i_1 = 0$
$P_1 = 0$	$EQ_1 = 1504$	$A_1 = 1504$	$Y_1 = 1504$	$\Delta mpc^i_1 = 0$

Table 4.2: Starting point setting.

The model was validated according to the business cycle stylized facts presented by Kydland and Prescott (1990), which are also based on the definition of the business cycle by Robert Lucas. However, we have to take into the consideration that we work in this simple ACE model with constant prices. Thus, there could be some deviations from the stylized facts caused by the influence of the price level. For validation, we used following stylized facts (Kydland and Prescott, 1990):

(SF1) The inventory stock lags the business cycle (the lag is about half a year).

(SF2) The change in business inventories behaves in a procyclical manner.

(SF3) The consumption of nondurables and services, consumer durable investment and fixed investment is procyclical.

(SF4) The largest component of total output is consumption of nondurable goods and services. This series is relatively smooth (its volatility is low).

(SF5) The higher volatility in the aggregate output is due to investment expenditures.

(SF6) The labor input measured as the aggregate hours-worked is strongly procyclical.

(SF7) labor income is strongly procyclical.

(SF8) The real wage behavior is strongly procyclical.

(SF9) The volatility in labor input measured as the aggregate hours-worked is different for higher and less skilled workers, the volatility of the less-skilled group is higher.

4.4 Simulation results

The presentation and interpretation of the simulation results is mainly focused on analyzing the main and partial goals of the thesis, e.g. on analyzing the influence of fluctuations in consumer confidence on the aggregate income. Thus, we follow during the simulation analysis, step by step, the propagation mechanism of the effect of consumer confidence on the economic activity (observed on the aggregate income). The spread of the consumer's confidence is evaluated first. Further, the relationship between the consumer confidence and the aggregate demand observed on the aggregate indicator is analyzed. Finally, the relationship between the consumer confidence, aggregate demand and the aggregate income is investigated. In addition, to support the validation of the model, the behavior of the main macroeconomic variables are examined.

The second part of this chapter is devoted to the analysis of sensitivity. Because of the focus on the impact of consumers' confidence on the aggregate income, the sensitivity on the parameter α_y is in the center of attention (this parameter determines the weight assigned to the influence of the neighborhood on the agent's confidence). In addition, to support and analyze the stability of our results, the sensitivity for other model parameters is provided too.

We present the simulation results from different points of view. Firstly, we would like to present the development of initial macroeconomic variables in the model during one simulation. The reason is following, in each simulation the business cycle movement is random, thus, the turning points in business cycles do not coincide in the same macrosteps among all simulations.[23] Therefore, taking an average value in the certain macrostep from all simulations mean taking an average value across all possible states in the business cycle. Averaging the values of observed variables could distort the information how the variables behave during the cyclic movement. Thus, the results are firstly presented on the simulation from one run, where the cyclic behavior is maintained. For practical reasons the time horizon on the y axis was, in some cases, chosen just from 0 till 200 macrosteps to make the evolvement of observed variables more visible. By the first observations the influence of the starting point should be taken into consideration.

Further, we add the statistical evaluation of variables during 150 macrosteps based on the simulations driven on 100 runs. To decrease the impact of the starting point, the simulation were

[23]For example, the first peak occurs in the first simulation in the macrostep 10, in the second simulation in macrostep 12, etc., and with growing amount of macrosteps the differences in timing are accumulated and bigger.

driven for 200 macrosteps and for the statistical evaluation the data from first 50 observations were dropped (e.g. the macrostep zero in these graphs is macrostep 50 from the simulation). In each graph the solid line represents the mean value of the observed variable in macrostep t and the dashed lines represent the minimum and the maximum from all simulations achieved in macrostep t. We were considering to depict in the graph also the standard deviation and the first and the third quantile, however it was not much readable from the graph. We believe that observing extreme values can be, in this case, more useful. The mean value of the observed variable with other descriptive statistics obtained from the statistical evaluation are further presented in tables.

4.4.1 The spread of the consumer confidence

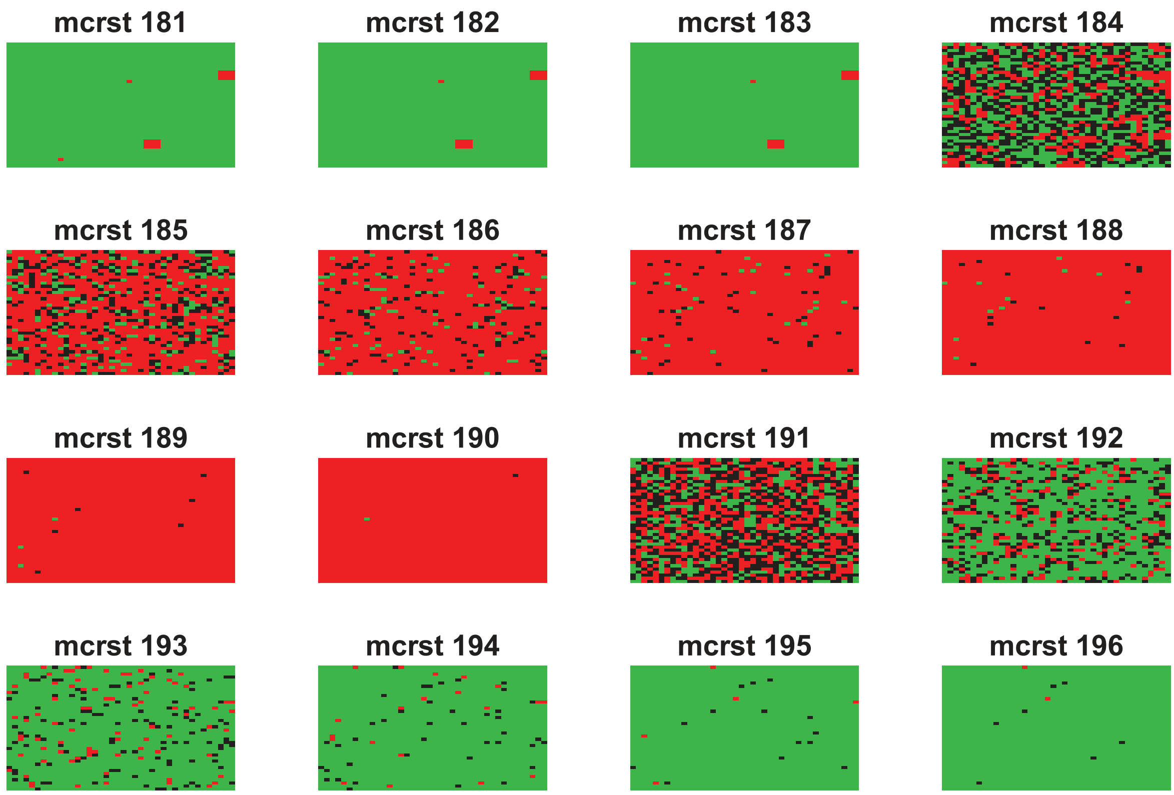

Figure 4.3: The optimists, stable agents and pessimists in the lattice.

The ACE model was constructed to investigate the impact of the spread of waves of optimism/pessimism from the micro level on the economic activity. Hence, let us start with the analysis of the spread of consumer confidence in the model. The spread of confidence on the lattice from one run can be seen in Figure 4.3. For more transparency, we are presenting the confidence in the lattice from macrostep 181 till 196, with the step of the length 1 macrostep. The stable agents in the figure are black, the pessimists are red and the optimists are green. In the macrostep 181 we can see that there is a majority of optimists in the society. The end of the wave of optimism could be considered around the macrostep 184, where the confidence in the society is mixed (the speed of the change in the confidence is also dependent on the number of steps during microsimulations, where the change of confidence is simulated). The pessimistic wave is between the macrosteps 185 and 191, with the peak in 190. From the macrostep 192 the confidence in the society is becoming optimistic anew, converting into the wave of optimism.

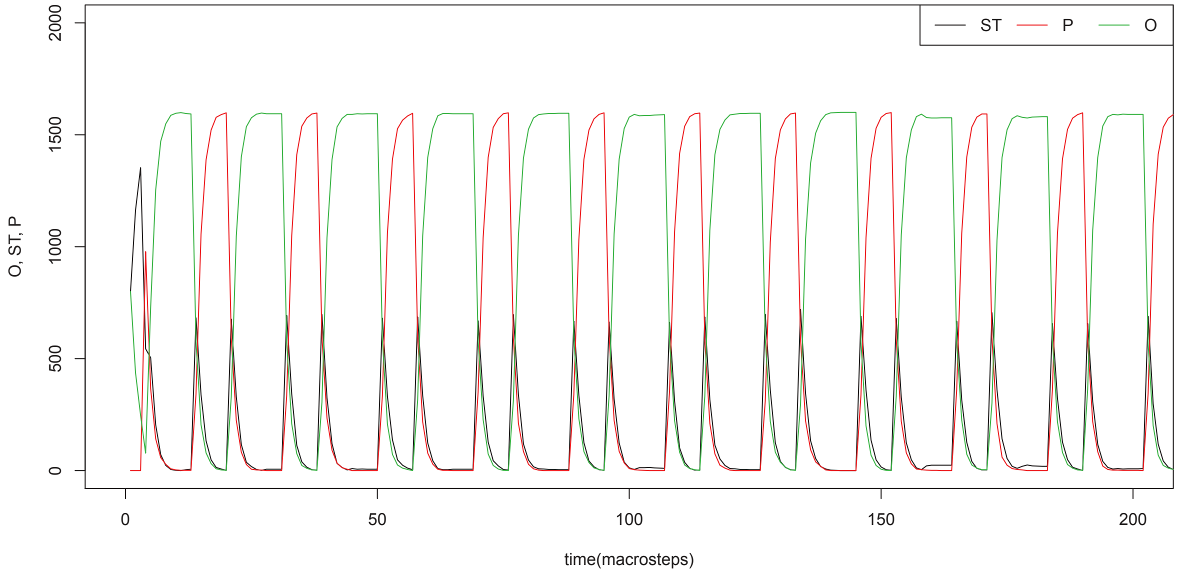

Figure 4.4: The amount of optimists (O), stable agents (ST) and pessimists (P) during one run.

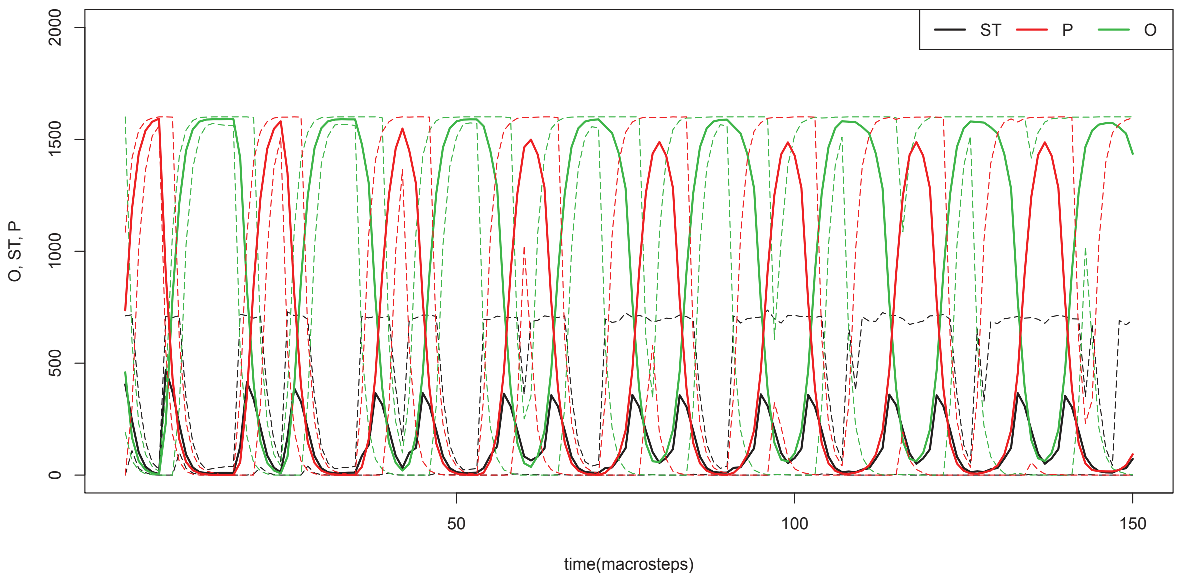

Figure 4.5: The amount of optimists (O), stable agents (ST) and pessimists (P) - statistical evaluation.

We can further observe the spread of the confidence in the aggregated form. We present the development of the total number of optimists, stable agents and pessimists in the society during one run in Figure 4.4. We can see that the agents become optimists until the moment when the majority of the society is optimistic (green line), then slowly starting to change into the society mixed of stable agents (black line), optimists and pessimists (red line). Then, the optimistic wave disappears and the spread of the pessimism decreases the amount of stable and optimistic agents till zero. After reaching the peak amount of pessimistic agents the confidence in the society is turned back into the mixed case of optimism, stableness and pessimism. It also shows that the amount of stable agents in its peak changes during macrosteps. This is consistent with the randomness of the confidence spread.

Statistics	O	P	ST	$CONF$
Mean	939.102	530.54	130.357	408.562
Standard deviation	693.687	657.339	211.265	1334.901
Median	1393	81	19	1313
Min	0	0	0	−1600
Max	1600	1600	737	1600
1st Quantile	84	1	8	−1305
3rd Quantile	1586	1388	130	1585

Table 4.3: The amount of optimists (O), stable agents (ST), pessimists (P) and the indicator of confidence ($CONF$) - descriptive statistics.

The statistical evaluation is presented in Figure 4.5 and Table 4.3. In Figure 4.5 we can see that the mean values of the amount of optimists, pessimists and stable agents (solid lines) follow the similar pattern described on the simulation from one run above. The maximal and minimal values of the amount of pessimists and optimists (dashed lines) confirm that the peak of optimism and pessimism does not necessary happen when all agents are optimists or pessimists (the peak would be M) but could be lower. Thus, it is sufficient when the majority of agents are optimists (i.e. critical mass) and the growing optimism in the society will turn into the fall. Vice versa, it is sufficient when the majority of agents are pessimists and the growing pessimism in the society will turn into the fall. Further, the randomness of cyclic movement in consumer confidence could be well observed. Because the starting point is the same for all simulations, the development of confidence is similar for all runs at the beginning, however, with the growing macrosteps the diversity increases.

The descriptive statistics of the variables are presented in Table 4.3. What could be interesting is that the mean value of the amount of optimists is much higher than the mean value of the amount of pessimists. Nonetheless, if we look back into Figure 4.4 and Figure 4.5, we can see that during simulation of one run and also during statistical simulations, the amount of optimists stays longer in its upper peak than in its bottom and vice versa, the amount of pessimists is longer in its bottom than in its peak. This could explain the difference between the mean values of these variables, and as well between their medians and quantiles. Further, it supports the idea that the waves of optimism (measured from the moment when the indicator of confidence $CONF$ firstly cross the value 0 from the negative to the positive values until the moment when it cross back from the positive values back into the negative ones)[24] are longer than the waves of pessimism (measured from the moment when the indicator of confidence $CONF$ firstly cross the value 0 from the positive to the negative values until the moment when it cross back from the negative values back into the positive ones). The standard deviation of the amount of optimists and pessimists is similar. The stable agents never achieve the maximum of M agents. The indicator of confidence in society ($CONF$) achieves both its extremes (M and $-M$) and its mean value is 408.562, which is in line with the conclusion that the optimistic periods are longer than the pessimistic ones.

4.4.2 The aggregate demand

Following the first partial goal of this thesis, we would like to find out if the spread of the optimistic/pessimistic waves in consumers' confidence can generate the cyclic movement in the aggregate demand. The simulation of the development of these variables from one run is presented in Figure 4.6 and the statistical evaluation in Figure 4.7. We can see from Figure 4.6 that the confidence indicator $CONF$ is a leading variable for the aggregate demand during most of the macrosteps.

However, it seems that in case of downturns in both variables, the turn is firstly observed in the aggregate demand, followed with the turn in the consumer's confidence with a lag. The interpretation of this behavior is not very simple because all the variables are developing within the complex system. It could be explained with the fact that when the agents are for more succesive periods pessimists, they try to maintain their consumption and change their marginal propensity to consume (according to (4.12)). Thus, they remain pessimists, supporting the spread of the pessimism in the society and the fall in the aggregate confidence (measured by $CONF$), but they do not decrease their individual demand for consumption spending, thus slowing down the fall in the aggregate demand. This can explain why the aggregate demand stop at some level while the aggregate confidence is still falling. Further, why the aggregate demand starts to grow sooner than the confidence? The aggregate demand is a sum of individual demands and the individual demand is a function of the past consumption spending, consumer's confidence and his/her income. During the fall the firm has always a big inventory stock generated from unsold part of the aggregate supply. Once the aggregate demand remains on the same level, the target production of the firm is less limited by the huge inventory and when the firm gets rid of this burden, it can even increase the production. With the increased production the consumers' income increases. Thus, their consumption demand and hence the aggregate demand immediately increases. The consumer's confidence is influenced by the change in his/her income but also by the confidence in the neighbourhood. Thus, a pessimistic agent with all pessimists around will not switch the confidence immediately after the positive change in his/her income. The change in the income of consumers will have a positive effect on the consumers'

[24]The exact definition could be found in Chapter 5.1.

confidence, but with some time lag, caused by the influence of the neighbourhood.

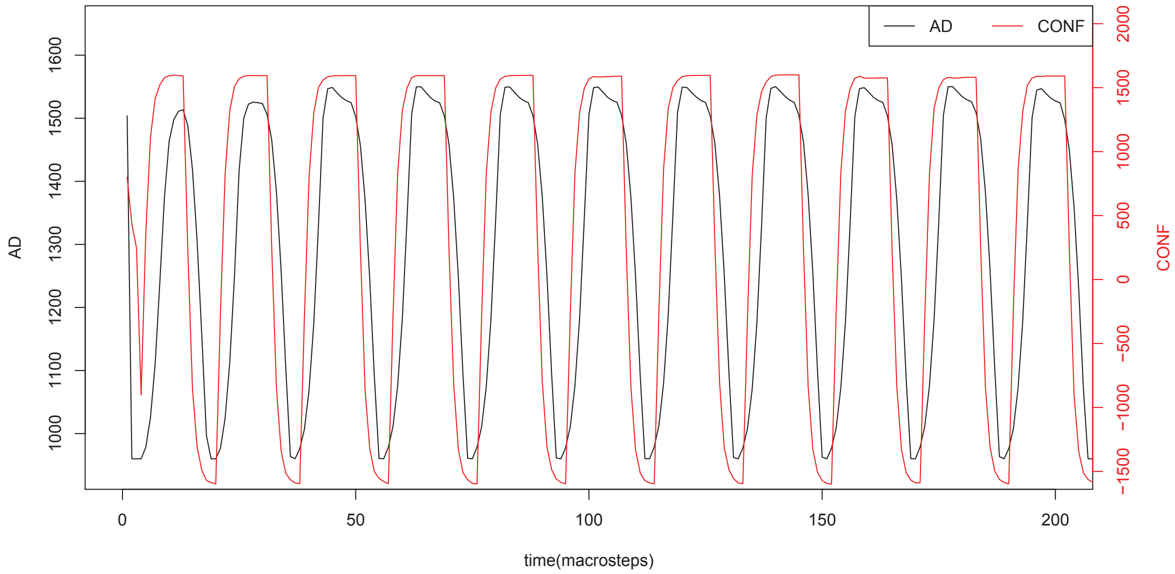

Figure 4.6: The consumer confidence indicator versus aggregate income.

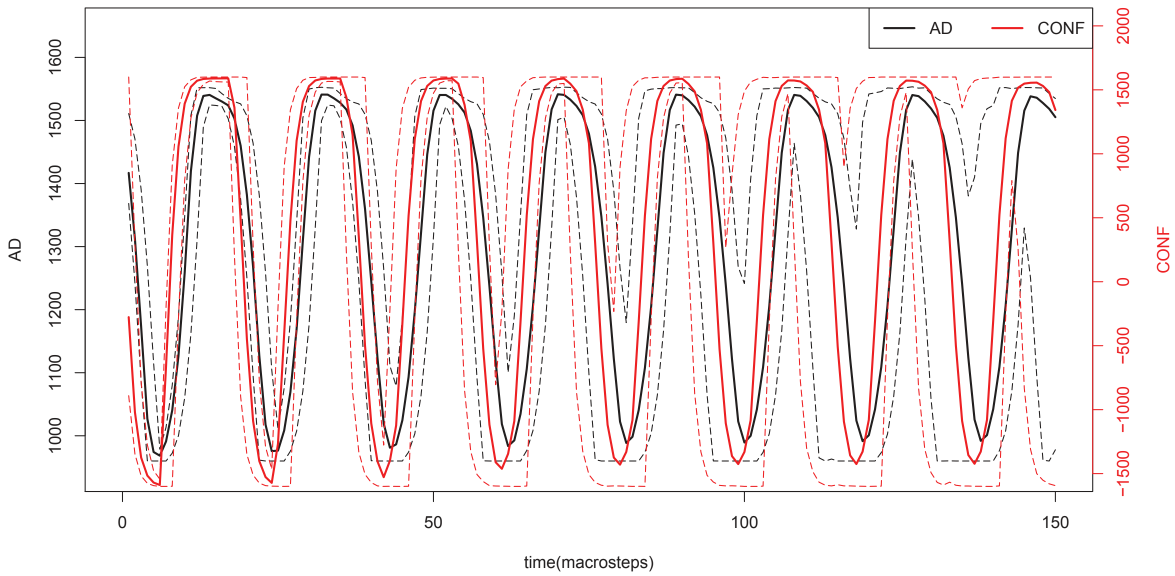

Figure 4.7: The consumer confidence indicator versus aggregate income - statistical evaluation.

The confidence indicator and the aggregate demand seem to reach their peaks in the same macrosteps. In case of confidence indicator $CONF$, we can observe high slowdown in the growth before reaching this peak. This slowdown could be considered as a first sign of the future switch in the aggregate demand. After reaching the peak, the aggregate demand starts to decrease immediately. The confidence remains at its maximum for some periods, followed by the dramatic fall. The development of the mean values of both variables from Figure 4.7 confirms the lead of the confidence indicator to the aggregate demand. According to these results, the downturn firstly appear in the mean of the confidence, followed in the downturn in the aggregate demand. We cannot conclude that the optimism/ pessimism in consumers' confidence cause the fluctuations in the aggregate demand, however we can confirm that according to the achieved results both variables behave cyclically and their development seems to be interconnected.

4.4.3 The aggregate income

According to the propagation mechanism and the second partial goal of this thesis, we are further interested if the fluctuations in the aggregate demand can cause the fluctuations in the aggregate income. We cannot directly confirm the causality between these two variables. However, if there will be such causality, there should be a similar comovement in both variables observed, their fluctuations should follow a similar pattern in grow, fall and their turning points and the fluctuations in aggregate demand should be leading to the fluctuations in the aggregate income. Thus, we will analyze the simulation results if such pattern is observable. The causality between variables will be further investigated during the sensitivity analysis.

The development of these variables together with the development of the aggregate supply from the one run simulation is presented in Figure 4.8. We can observe the cyclical behavior of all these variables. The development of the aggregate demand is similar to the development of the aggregate income. In most of the cases the evolvement of these two variables is nearly equal. The value of the aggregate demand is on its peaks lower than the aggregate income, thus the part of the aggregate income is saved. Vice versa, during the bottoms of the aggregate demand, the aggregate income is lower than the aggregate demand, thus the aggregate demand is assumed to be partially financed from the agents' assets. It seems that before the downturn in both variables, the aggregate demand stops at some level while the aggregate income is still falling. This corresponds to the agents, which after some successive periods of pessimism prefer rather to maintain their consumption spending, even when their income is falling. The change into the growth seems to happen in both variables at the same time. This is again in line with the explanation presented before, that the growth in the aggregate income is immediately projected into the consumers' demand, thus into the aggregate demand.

In case of the peaks, there is a slowdown in the growth of the aggregate demand (caused by the switch in the marginal propensity to consume of optimists) while the aggregate income stops at some level (the production possibility of the firm is reached). The fall is firstly observed in the aggregate demand (the income of consumers remains constant, but the spread of optimism causes that more agents are changing their marginal propensity to consume in favor of higher savings), followed by the aggregate income (the lower aggregate demand enters through the market result the target production function of the firm and thus the production is decreased). The same conclusions can be made from the development of the mean values of these variables, presented in Figure 4.9.

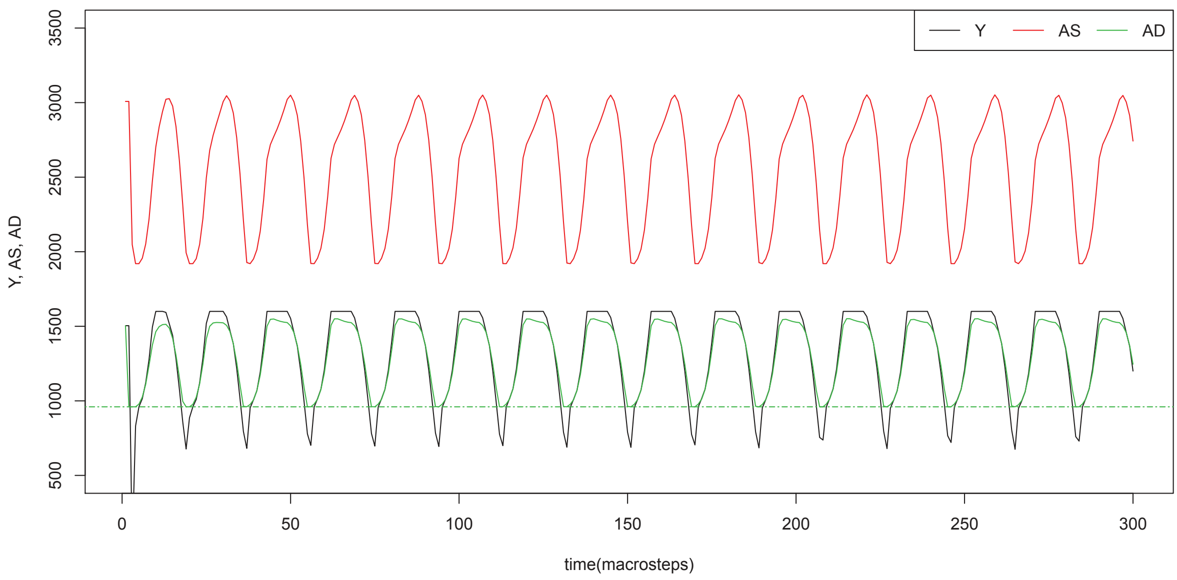

Figure 4.8: Aggregate income (Y), aggregate supply (AS) and aggregate demand (AD) during one run.

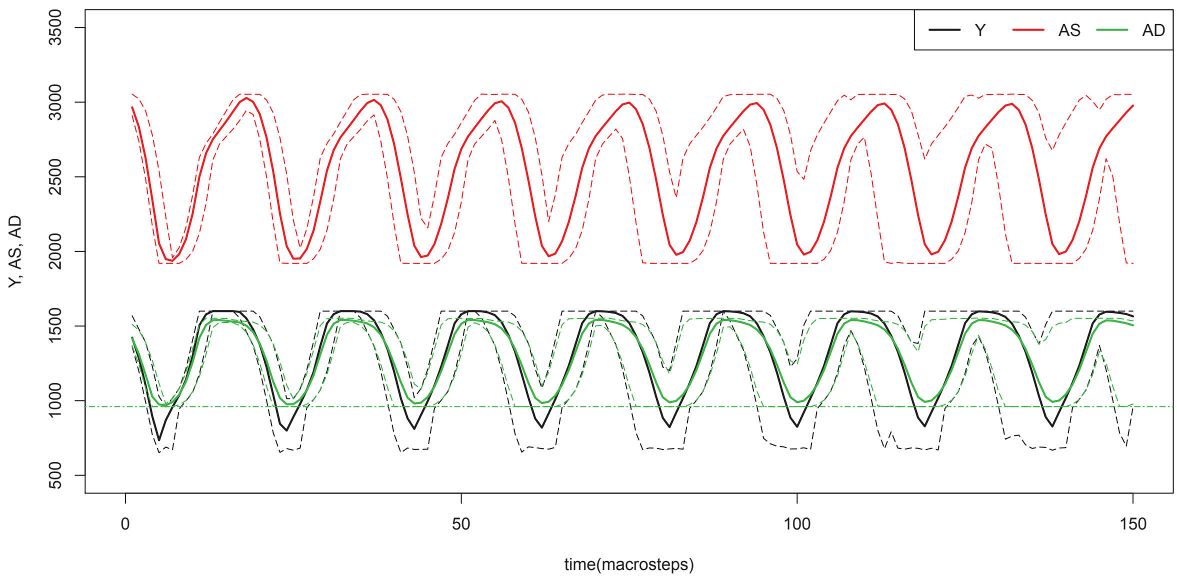

Figure 4.9: Aggregate income (Y), aggregate supply (AS) and aggregate demand (AD) - statistical evaluation.

The mean values of both variables presented in Table 4.4 are very similar. The mean value of the aggregate demand is slightly bigger than the mean value of the aggregate income, this could be probably explained by the development of these variables during the bottom, when the aggregate income is much lower that the aggregate demand (some consumers prefer to maintain their consumption level and finance it also from their savings). The downturn in the mean value of the aggregate demand is not reaching its possible minimum (the green dot-and-dashed line, the situation, when all agents consume their minimal amount of consumption). The minimal value of the aggregate income is lower than the minimal value of the aggregate demand, in case of maximum it is vice versa. The volatility of the aggregate income is quite high compared to the aggregate demand.

Statistics	Y	AS	AD
Mean	1307.52	2548.872	1307.996
Standard deviation	301.959	400.009	227.399
Median	1393.07	2720.52	1372.592
Min	651.086	1920	960
Max	1600	3054.654	1553.379
1st Quantile	1015.66	2153.157	1076.569
3rd Quantile	1600	2903.318	1527.574

Table 4.4: Aggregate income (Y), aggregate supply (AS) and aggregate demand (AD) - descriptive statistics.

Considering the relationship between the aggregate income and aggregate demand, we can make the picture complete and observe the development of the aggregate supply too. The aggregate supply is in the simulation (in Figure 4.8 and in Figure 4.9) always higher than the aggregate demand. The aggregate supply is in each period consisting of the immediate production and inventory (4.17). The excess of the aggregate supply over the aggregate demand is in line with the firm strategy, when the firm tries to keep an inventory in the size of last realized sales as a buffer stock for unexpected fluctuations in the aggregate demand. We can see that at the beginning, when the aggregate demand starts to fall, there is a period when aggregate supply is still rising. This is caused by the accumulation of inventory. Later the inventory is reduced and the aggregate supply is closer to the aggregate demand (this is again implied by the firm strategy defined in (4.18)) . Thus, the aggregate supply is more volatile than aggregate demand. The dashed line in the Figure 4.8 indicates the minimum level of aggregate demand, which is ensured by setting the minimum value of individual demand for consumption spending. This lowest value can be thus the case when all agents demand only this minimal value in two successive macrosteps (because of consumption smoothing). The minimal value is equal to $0.6M = 960$.

The statistical evaluation presented in Figure 4.9 confirms the cyclic behavior of the aggregate supply too. We can see the dominance of the aggregate supply over the aggregate demand and the increase in the aggregate supply at the beginning of the fall of the aggregate demand (this could be explained by the accumulation of inventory, as in Figure 4.8) in Figure 4.9. All variables evolve cyclically.

Finally, we can look at the development of the confidence indicator in comparison to the development of the aggregate income in Figure 4.10, Figure 4.11 and Figure 4.12. The red dot-and-dashed lines in Figure 4.10 indicate the maximal (1600) and minimal (-1600) value of the confidence indicator. We can see that the changes in the consumer confidence nearly coincide with the cyclic movement of the aggregate income. During the peaks in the aggregate income the majority or all consumers are optimistic and during the downturns in aggregate income majority of consumers are pessimists. To complete the picture, we add into the Figure 4.10 also the indicator of marginal propensity to consume (MPC) and dot-and-dashed lines for its maximal and minimal values[25]. We can see that this indicator is close to its extreme values during the turns in the aggregate income. During the peak in the aggregate income the majority of consumers increases their share of the savings on their immediate income, during the downturn the share of immediate consumption on immediate income is increased.

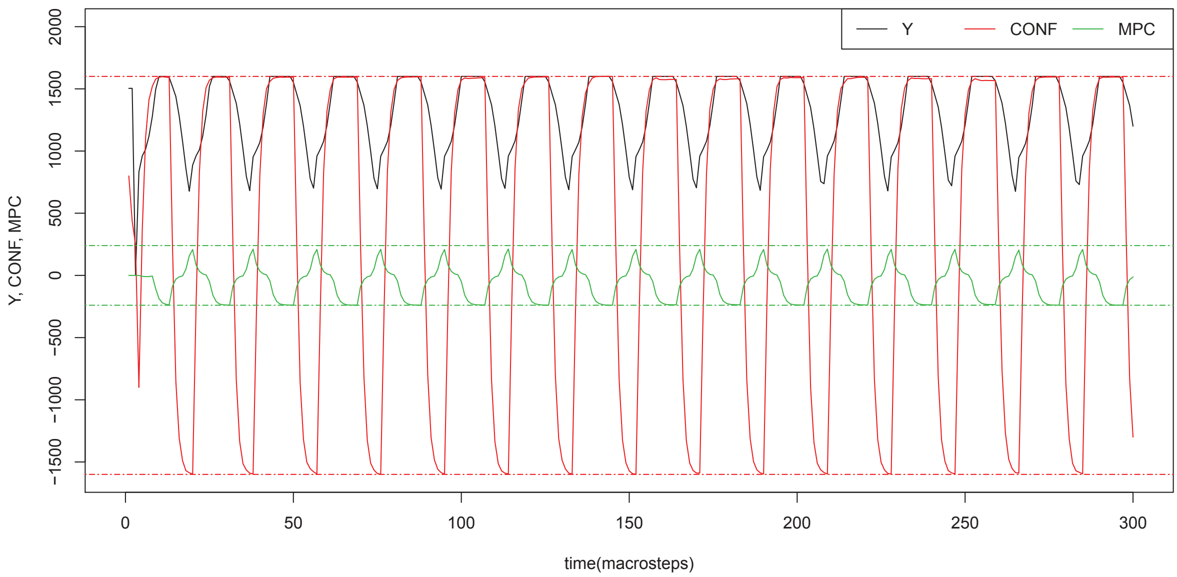

Figure 4.10: The consumer confidence indicator, aggregate income and marginal propensity to consume.

We present the development of the aggregate income versus the development of the indicator of confidence in Figure 4.11 and Figure 4.12. From these graphs we can try to evaluate if some of these variables are lagged or leading to the other. We can see that during the growth of the aggregate income the indicator of confidence could be assumed as a leading variable. The growth in the indicator of confidence means the spread of optimism among agents, optimistic agents are increasing their consumption demands and thus the aggregate demand. The firm reacts on the increasing aggregate demand by an increase in its production, which means an increase in labor demand and an increase in the individual and aggregate income. Thus, the growth of the confidence indicator could through the production provoke an increase in the aggregate income.

[25]The maximum value could be counted from the equations (4.12) and (4.13) as $1600 * 0.15 = 240$ and the minimum value $1600 * (-0.15) = -240$.

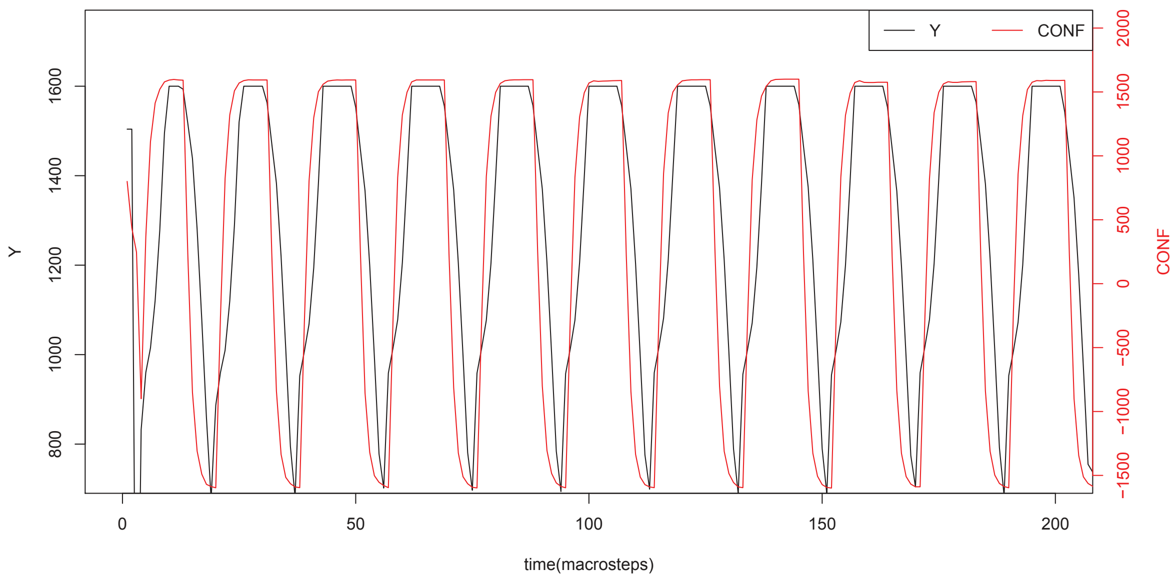

Figure 4.11: The consumer confidence indicator versus aggregate income.

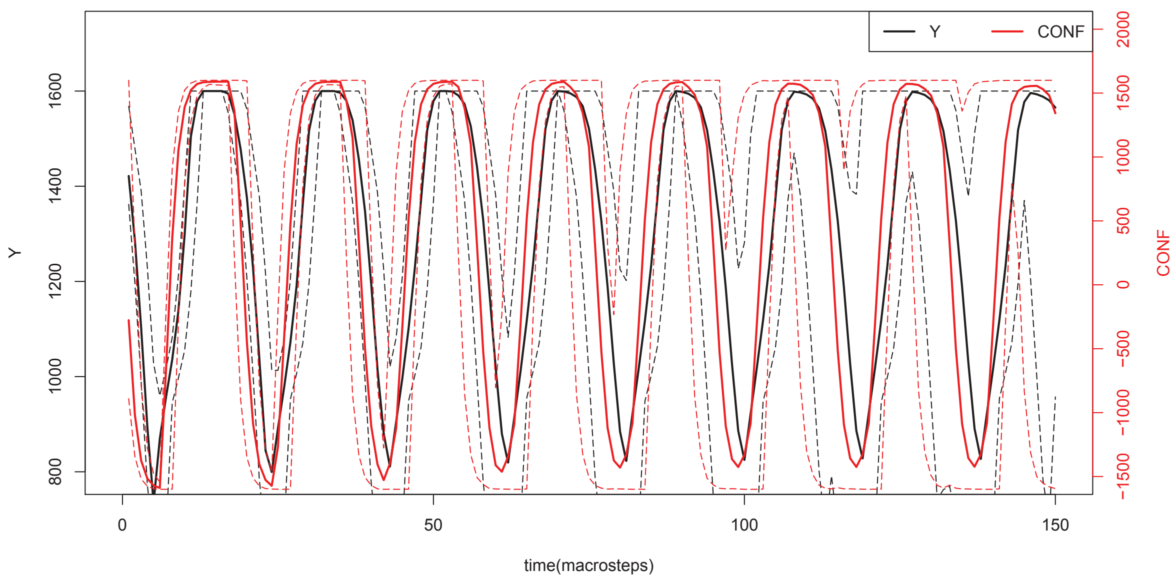

Figure 4.12: The consumer confidence indicator versus aggregate income - statistical evaluation.

At the peak, the aggregate income is the first decreasing, following by the indicator of confidence. During the peak, the production of the firm is always burdened by its production possibility. Thus, however the aggregate demand is increasing, the production and hence the aggregate income (the cost of production is equal to the aggregate income (4.20)) reach its maximum and remain at this level. We can see in Figure 4.10 that during this period, the indicator of marginal propensity to consume (MPC) is becoming negative, thus the agents start to prefer more savings to immediate consumption. Thus, the aggregate demand starts to fall (could be seen in Figure 4.8), the agents remain optimists with higher preference for savings, the confidence in the society is thus still high while the aggregate demand is already decreasing. After some period the aggregate demand decreases below the level of production possibility of the firm, causing the decrease in production and decrease in the aggregate income. So the aggregate income starts to fall first. The lower income has an influence on the confidence of agents, nevertheless, together with the impact of the neighbourhood the fall in confidence follows the fall in the aggregate income with some lag. Further, the indicator of confidence seems to be decreasing faster, becoming a leading variable anew.

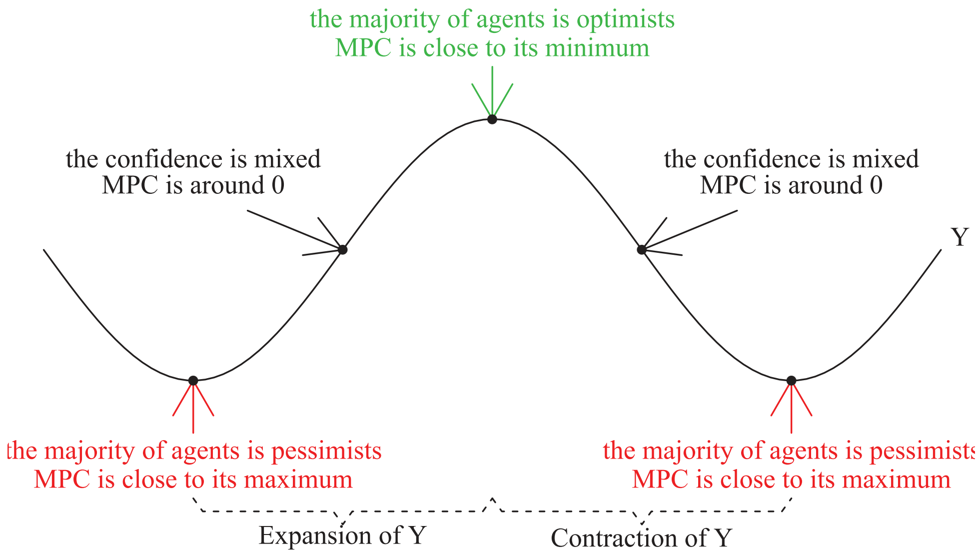

Figure 4.13: The cyclical movement of the aggregate income.

Following the simulation results, the scheme of the wave in the aggregate income could be understood as the scheme presented in Figure 4.13. According to the previously accepted definition, the waves of optimism/pessimism start when the aggregate confidence indicator ($CONF$) is around 0, e.g. when the confidence in the society is rather mixed, with some stable agents. According to Figure 4.13, the wave of optimism is at the beginning connected with the expansion in aggregate income. The confidence in society is growing until the majority of agents, e.g. "the critical mass" as was explained before, (not always all according to the simulations) are optimists. With the prolonged period of optimism, agents start to adjust their marginal propensity to consume in favor of savings. When a vast majority of them adjust their marginal propensity to consume in this direction, the aggregate income reaches its peak and starts to turn down. The decrease in the aggregate income is connected with the return to the society of mixed confidence and beginning of the pessimistic wave. The first phase of contraction starts with the spread of a wave of pessimism, until the majority of agents are pessimists. The prolonged period of pessimism by agents invokes the change in their marginal propensity to consume in favor of immediate consumption spending. When the vast majority of agents increases their marginal propensity to consume, the aggregate income reaches its bottom and turns up anew. The confidence in society is changing back into the state of mixed confidence. These results confirmed that the development of the consumers' confidence, the aggregate demand and the aggregate income are closely related. It is not confirming the causality of the fluctuations in consumers' confidence for the fluctuations in the aggregate income. However, the development of these variables is not rejecting it. This causality will be further investigated during the sensitivity analysis, while switching off the influence of the confidence in the agent's neighborhood.

4.4.4 Production and investment

We have already analyzed the relationship between the spread of the confidence, the aggregate income and the situation on the market with respect to the aggregate supply and aggregate demand. However, for validation of the model, we should control the development of other main macroeconomic variables in the model, if the development and the relationships among these variables are in line with generally observed behavior of these variables and in line with stylized facts introduced in Chapter 5.3. Thus, we will analyze the situation of the firm, consumers and the labor market next.

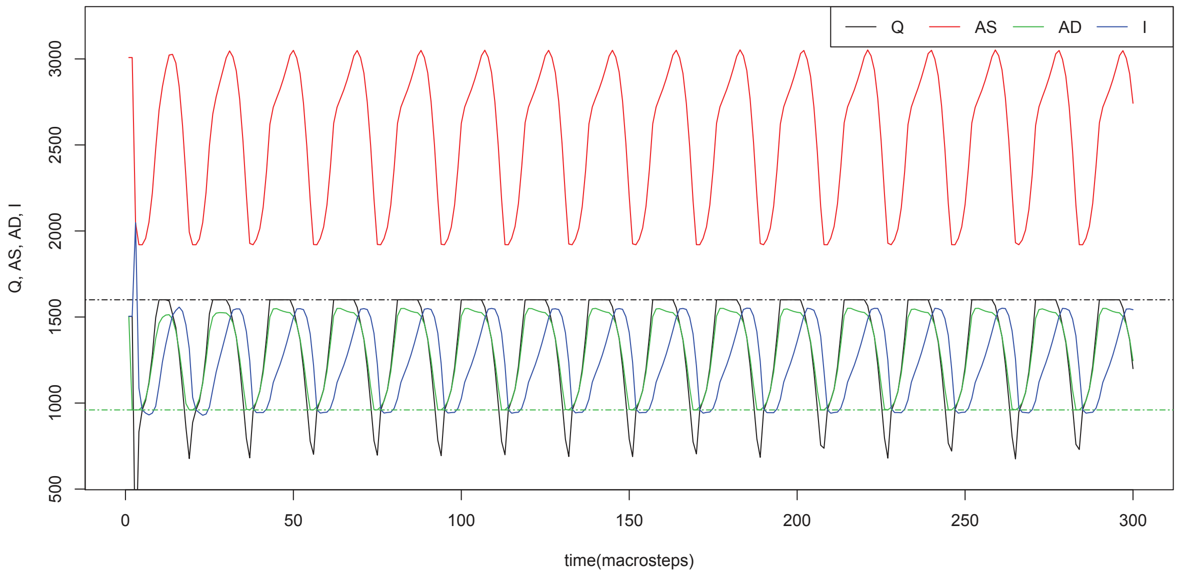

Figure 4.14: The aggregate supply (AS), production (Q) and inventory (I) during one run.

The aggregate supply and its components are presented in Figure 4.14. We can see the cyclical movement of the production, which, according to (4.20) coincides with the cyclical movement of the aggregate income. The volatility of the aggregate supply is higher than the volatility of production, which is in line with the definition of the aggregate supply as the sum of the production and the inventory (4.17). Both the production and the inventory are always nonnegative, thus, the volatility in the aggregate supply has to be either equal or higher than the volatility in the production. The black dot-and-dashed line in Figure indicates the maximal level of production limited by the amount of workforce. We can see that during expansions the production is limited by this maximal level. This confirms the sooner presented explanation that while aggregate demand is still growing, the aggregate income and thus the production is stopped by its maximum level. The development of inventory expresses the excess of the aggregate supply over the aggregate demand, which is growing during expansion in aggregate demand and decreasing during the contraction (different buffer stock target). These results are in line with Kahn and McConnell (2002), who stated that firms are usually trying to keep the inventory/sales ratio constant and their inventory varies with the economic activity. According to them, the inventory is strongly procyclical. Further, it is in line with the second stylized fact (SF2) that the changes is the inventory are procyclical.

For the comparison with the production, the aggregate demand was added into the graph. The green dot-and-dashed line indicates its minimum level, when the aggregate demand is based only on the minimum consumption demands of agents. According to the graph, the production is at its lowest level when the aggregate demand is at its minimum. We can see from the simulation results from one run (in Figure 4.14) that once the aggregate demand reaches its minimum, it stays on this level while the production and inventory are still falling. This is caused by the fact that the firm has a big inventory burden from the period of contraction which is limiting the production. The extreme values in the inventory are lagged to production. As the production corresponds to the aggregate income, the inventory lags the cycle in the aggregate income. This is in line with the first stylized facts (SF1).

In Figure 4.14 the new expansion starts usually when the firm deeply reduces its inventory. Kahn and McConnell (2002) state that the reduction of inventory during the recession could have a positive impact on the future growth of production. Once this burden is liberated and the inventory is decreased, the production can start to grow anew. As the production corresponds to the aggregate income, the growth of production cause directly the growth of the agent's income and thus the growth of the aggregate demand.

The statistical results, presented in Figure 4.15 and Table 4.5 confirm the interpretation made from the one run. All variables have a cyclical behavior, the production is mainly corresponding to the aggregate demand. According to the mean values, the aggregate demand turns down during the peaks sooner than the production, thus the aggregate demand could be considered as a leading variable. This was already explained sooner. At bottom, considering the mean values of the variables, it seems to be the production, which starts to grow first, supporting through the aggregate income the aggregate demand. The inventory is with respect to production and the aggregate demand lagged (in line with first stylized fact (SF1)) and the changes in the inventory behaves in a procyclical manner (in line with the second stylized fact (SF2)). We can see that the even minimal value of production is during the peaks in production always reaching the upper limit (M, limited from up by the amount of workforce). Thus, this limitation seems to be constraining.

The development of the aggregate demand and production is according to the statistical results presented in Table 4.5 very similar. The standard deviation, and thus the variance is slightly bigger in the case of production, this could be explained by the definition of the production target, which is following the fluctuations in the aggregate demand.

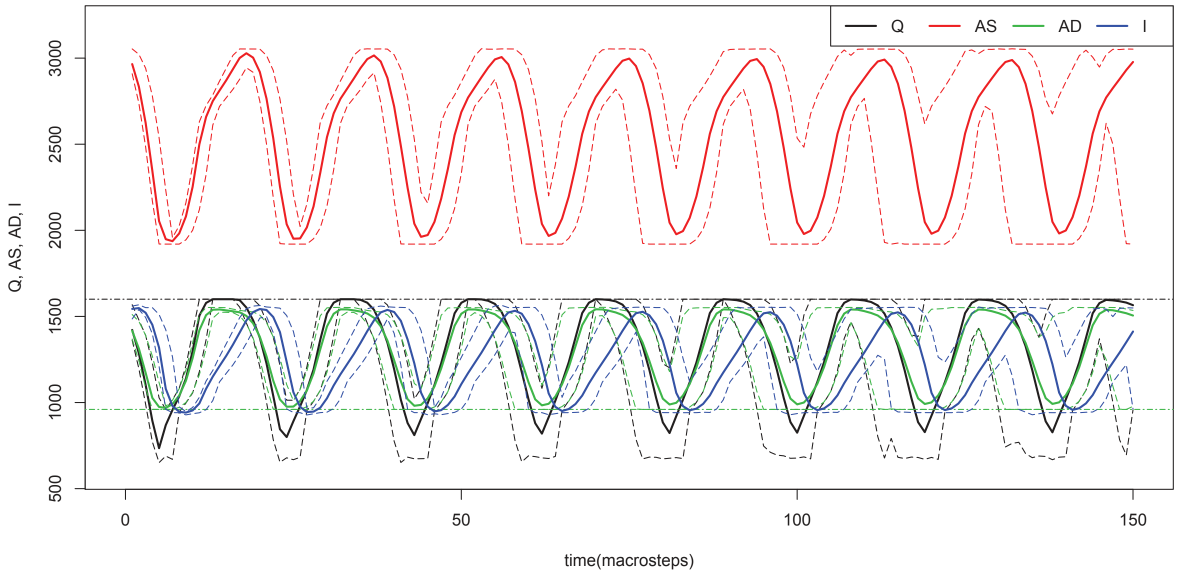

Figure 4.15: The aggregate supply (AS), production (Q) and inventory (I) - statistical evaluation.

Statistics	AS	AD	Q	I
Mean	2548.872	1307.996	1307.52	1241.352
Standard deviation	400.009	227.399	301.959	225.765
Median	2720.52	1372.592	1393.07	1230.046
Min	1920	960	651.086	927.819
Max	3054.654	1553.379	1600	1567.522
1st Quantile	2153.157	1076.569	1015.66	970.251
3rd Quantile	2903.318	1527.574	1600	1487.68

Table 4.5: The aggregate supply (AS), production (Q) and inventory (I) - descriptive statistics.

4.4.5 Consumption and savings

The distribution of the aggregate income into savings and consumption is presented in Figure 4.16. The consumption behaves in the procyclical manner in line with the third stylized fact (SF3). We can see that the aggregate income is during its expansion greater than the aggregate consumption, during its contraction is dominated by consumption, so the volatility of consumption spending is lower than the volatility of the aggregate income. This behavior is also visible in the statistical evaluation in Figure 4.17. The higher smoothness of the aggregate consumption with respect to the aggregate income is in line with the forth stylized fact (SF4). The lower variance of consumption in comparison to the variance of the aggregate income is also confirmed by the statistical results presented in Table 4.6. This could be explained by many factors.

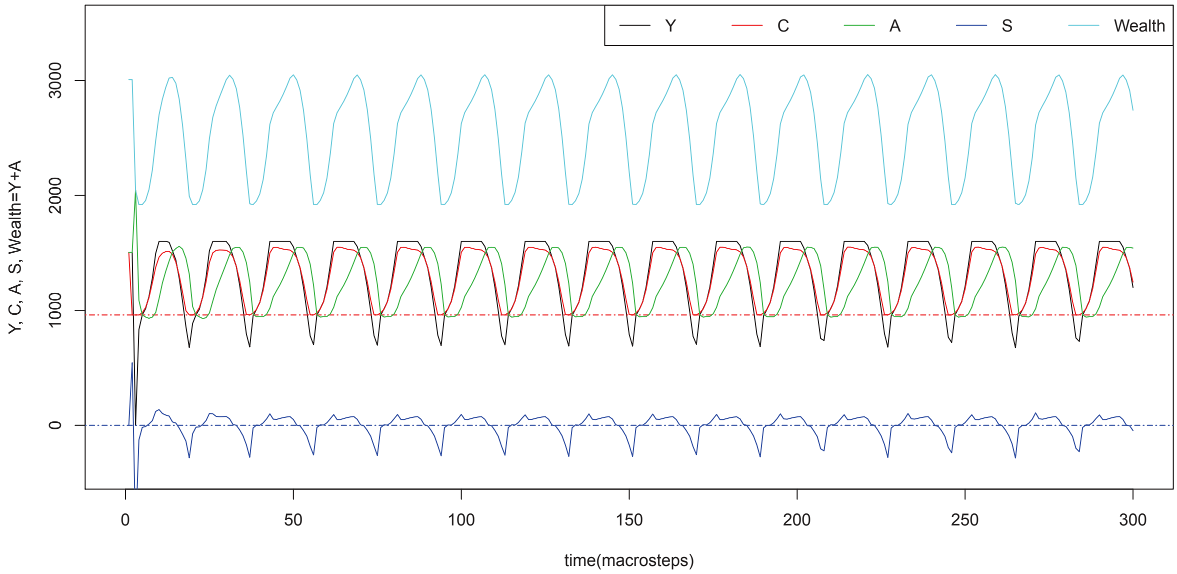

Figure 4.16: The distribution of consumer's income during one run.

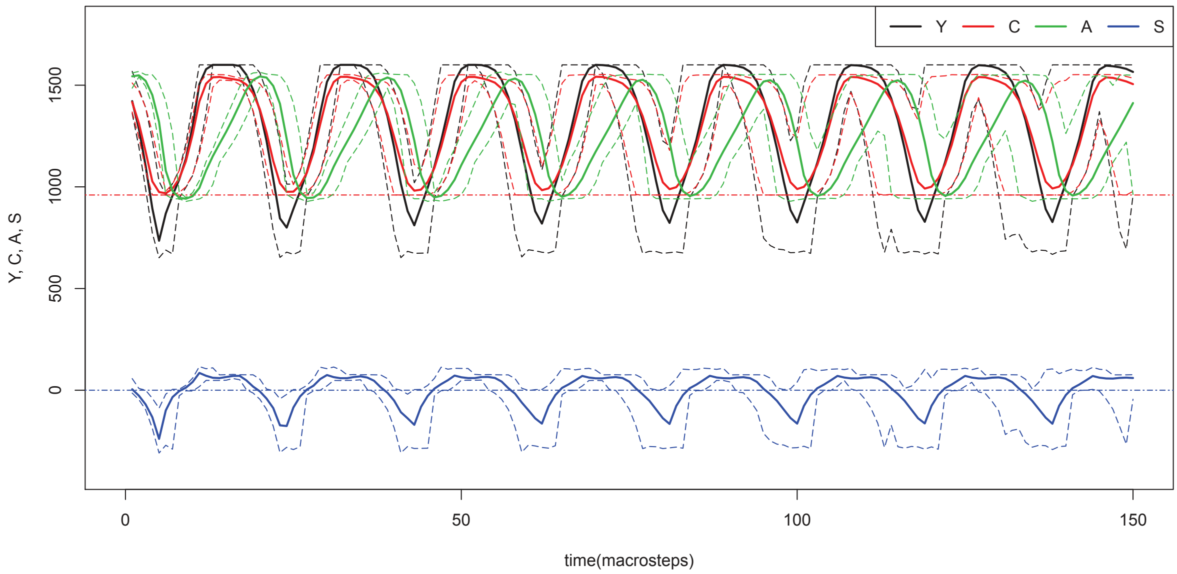

Figure 4.17: The distribution of consumer's income - statistical evaluation.

Firstly, there is a smoothing in consumption function, hence the consumption is not reflecting the change in income immediately. Secondly, according to the marginal rate of consumption setting, the spread of optimism is connected with the growing preference for postponed consumption and the spread of pessimism with the growing preference for the immediate consumption even for the cost of reducing assets. We are adding into the graph (Figure 4.16) also the variable "Wealth" which represents the budget of consumers in each macrostep t, computed as a sum of aggregate income together with their aggregate assets. We can see from the graph that although the income of consumers could be lower than their consumption spending, their wealth is much bigger. Therefore, keeping high consumption spending even for the cost of reducing assets (and wealth as well) could be preferred. The dashed line in Figure 4.16 and Figure 4.17 indicates the minimal value of consumption, which corresponds to the situation when all agents demand only the minimal level of consumption spending for at least two successive periods. However, from the simulation of one run it seems that in a contraction of the economic activity, the consumption spending reaches this level. From the maximal value presented in Figure 4.17 we can see that this minimal level of consumption is not necessary reached at the bottom of the contraction.

Further, we can analyze the development of the assets and savings. We have added into the graph the dashed line in 0 for better orientation when the savings are negative. We can see that the phase of growth in the aggregate income starts with the zero savings, thus the income of consumers is big enough to finance their consumption demand. This corresponds with the behavior of the firm. The firm in the contraction firstly reduces its inventory burden and after, with the aggregate demand stopped at some minimum level, is able again to increase the production for this level. During the phase of contraction the savings are positive, thus the assets of consumers are growing. We can see the decrease in the savings during the peak when consumption is decreasing. This decrease is caused by the change in the marginal propensity to consume in favour of savings. During the contraction in the aggregate income, the savings are slowly falling into negative values, contributing to financing the consumption of an agent. This is in line with Pollin (1988), who presented the idea that the decrease in income could lead to necessity to borrow to maintain the consumption. The mean value of savings is according to the statistical results presented in Table 4.6 very close to zero and negative. This is in line with the observation that the mean value of the aggregate income is lower than the mean value of the aggregate consumption spending. Thus, the increased consumption is financed by negative savings. Because this value is close to zero, we can consider that the aggregate income and consumption spending could be in the long run balanced (e.g., there is no growing or decreasing trend in the assets of an agent, the fluctuations in agent's consumption are reflecting the fluctuations in his/her assets and the sum of agent's incomes across the long horizon is matching the sum of his/her consumption spendings.)

Statistics	Y	C	A	S
Mean	1307.52	1307.996	1241.352	−0.476
Standard deviation	301.959	227.399	225.765	90.099
Median	1393.07	1372.592	1230.046	22.226
Min	651.086	960	927.819	−308.914
Max	1600	1553.379	1567.522	116.308
1st Quantile	1015.66	1076.569	970.251	−19.382
3rd Quantile	1600	1527.574	1487.68	58.619

Table 4.6: The distribution of consumer's income - descriptive statistics.

Following the model identity equation (4.30) the savings are equal to the changes in the firm's inventory, thus to the investment of the firm. We can see in both Figure 4.16 and Figure 4.17 that the volatility in the aggregate income is higher due to the high volatility in savings, e.g. in the firm's investment. The estimated volatility of these series is also presented in Table 4.6. These results are in line with the fifth stylized fact (SF5).

4.4.6 Employment

As the aggregate income is always uniformly distributed among all agents, we measure the employment in the model in the form of "hours worked", respectively as the share of producing labor on its potential. We observe the amount of work provided by agents L_t and its share on M, this express the ratio of labor force which was used in production in macrostep t. From the equations (4.19) and (4.20), with the setting $a^L = 1$ follows that the amount of work of all agents L_t is equal to the production and aggregate income. Thus, the labor will grow and fall with the aggregate income just from the definition. This is also in line with the sixth stylized fact that the labor input measured in hours-worked is strongly procyclical (SF6) and that the labor income is strongly procyclical (SF7). As this income is uniformly distributed among agents, the real wages behave in the procyclical manner too (SF8). The last stylized fact about the volatility of less-skilled workers will be considered later in the extended version of the model where the heterogeneous types of workers are considered.

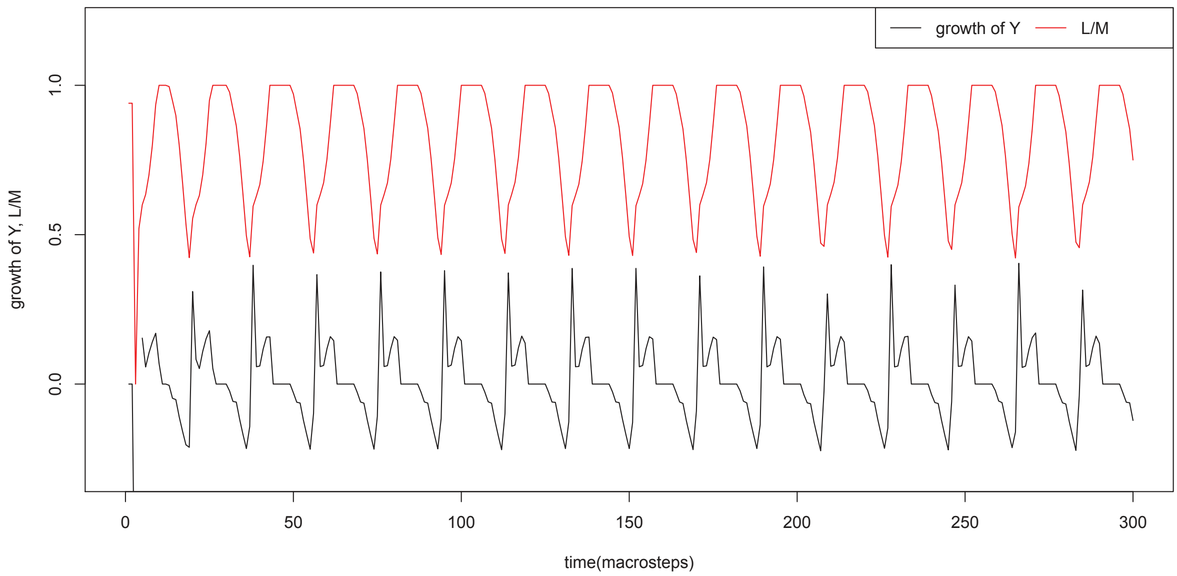

Figure 4.18: The aggregate income (Y) and labor (L/M) during one run.

We can further compare the growth rate of income with the approximation of an employment rate (L_t/M). We present the comparison in Figure 4.18 and Figure 4.19. We can see from the results from one run as well as from the mean values in the statistical evaluation in Figure 4.19 that positive growth rates of aggregate income are connected with high values of "employment" and negative growth rates of aggregate income with a decreasing level of "employment". These results are in line with the Okun's law. The rate of unemployment in the model could be approximated by the share of unused labor force in comparison to its potential, e.g. $(M - L_t)/M$). As the value of L_t is equal to the production and the aggregate income, the rate of unemployment expresses the share of unrealised income too.

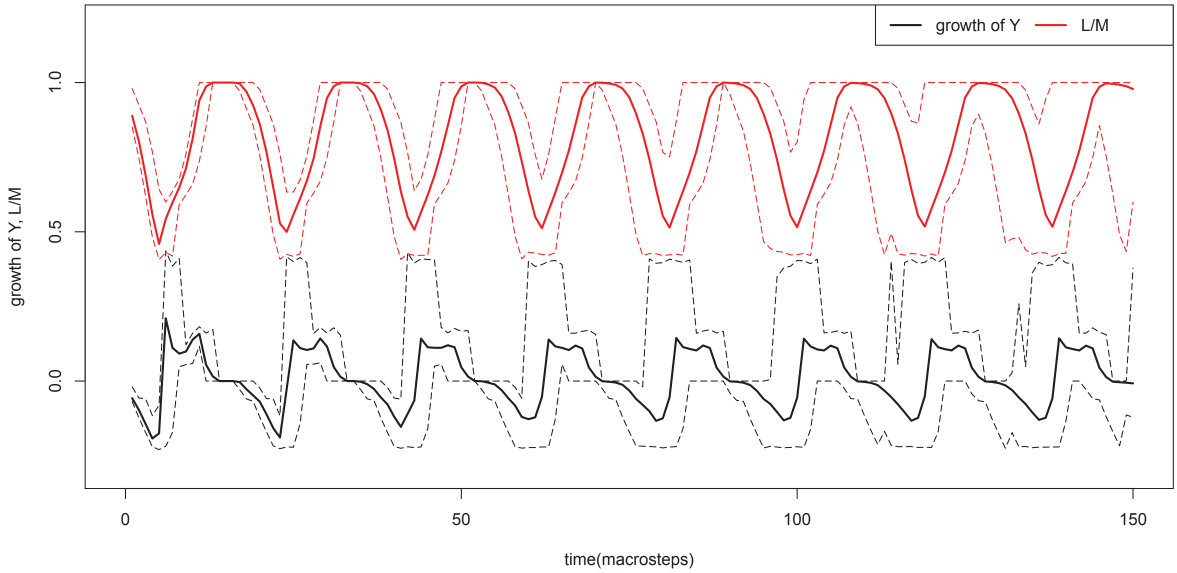

Figure 4.19: The growth rate of the aggregate income (Y) and labor (L/M) - statistical evaluation.

Statistics	growth rate of Y	L/M
Mean	0.008	0.817
Standard deviation	0.13	0.189
Median	0	0.871
Min	-0.23	0.407
Max	0.436	1
1st Quantile	-0.062	0.635
3rd Quantile	0.062	1

Table 4.7: The growth rate of the aggregate income (Y) and labor (L/M) - descriptive statistics.

The simulation results from the baseline model were in line with all stylized facts (SF1)-(SF8)[26] and also in line with the results from other studies (Kahn and McConnell, 2002, Pollin, 1988). Thus, we take the baseline version of this model as validated.

4.4.7 Business cycle

Because we are mainly interested in the cyclic movement of economic activity, we are presenting also some statistical evaluation of it in the Table 4.8. We define the business cycle according to the fluctuations in the aggregate income. Although the institutions which measure the business

[26]There is only one stylized fact which was not approved, the last one focused on the less-skilled workers, which is in the baseline version of the model irrelevant.

cycle movement (for example National Bureau of Economic Research, NBER) usually observe several consecutive periods to determine the particular turning point in the business cycle, we can define this turning point more easily. If we look into the Figure 4.18 of the growth rate of the aggregate income, we can see that once it grows and crosses the zero, it is the beginning of the expansion phase in the aggregate income and it is not coming back into negative values until the whole expansion phase is not finished. In case of contraction, we can see that the growth rate falls from positive numbers into the negative ones, but remains unchanged from some period on the zero rate. However, after reaching zero, it is again not coming into the positive numbers until the whole phase of the contraction in the aggregate income happens. Thus, we can define the turning points in business cycle just according to the crossing the zero line.

The upper turning point is set as a moment when the growth rate of the aggregate income firstly changes from the nonnegative to negative value. The lower turning point in the business cycle is defined as a moment, when the growth rate of the aggregate income firstly switches from the nonpositive values into the positive value[27]. The phase of expansion is measured from the macrostep which corresponds to the lower turning point into the macrostep, which is one step before the macrostep corresponding to the following upper turning point. By analogy, the phase of contraction is defined from the macrostep which corresponds to the upper turning point into the macrostep, which is one step before the macrostep corresponding to the following lower turning point. The full business cycle consists of the phase of an expansion and a contraction.[28]

Because we want to measure, for example, the amount of cycles during one run, we should consider only full business cycles. Thus, we are building the sample for estimation in the following way. Firstly, we use the data obtained from statistical simulations, where the observations from first 50 macrosteps were dropped. From each simulated run (now without first 50 observations) we take only the data covering full business cycles, e.g. the first observation in the subset is defined as a first lower turning point and the last observation of the subset as the last lower turning point. The observations before and after these turning points, which are parts on non-complete business cycles, were dropped. On the basis of these data we have measured following variables:

$Count$ = count of full business cycles in one simulation run,

$Period$ = the length of one full business cycle expressed in number of macrosteps (e.g. in case there are three full business cycles during simulation of one run we have three observations of this variable etc.),

$Duration^E$ = the duration of expansion in the full business cycle expressed in number of macrosteps,

[27]The definition of the business cycle which is used in this work was already presented in Chapter 3.2.

[28]Business cycle is usually defined with four phases, the phase of expansion, the peak, the contraction and the trough. As we are interested just to in the cyclic movement and we would like to count just number of cycles, two phases of the business cycle are adequate for our analysis.

$Duration^C$ = the duration of contraction in the full business cycle expressed in number of macrosteps,

$Amplitude^E$ = the difference between the aggregate income at the end of preceding contraction (measured at the last macrostep of contraction) and the aggregate income at the end of the expansion (measured at the last macrostep of expansion),

$Amplitude^C$ = the difference between the aggregate income at the end of preceding expansion (measured at the last macrostep of expansion) and the aggregate income at the end of the contraction (measured at the last macrostep of contraction).

Statistics	$Count$	$Period$	$Duration^E$	$Duration^C$	$Amplitude^E$	$Amplitude^C$
Mean	7.01	18.927	11.947	6.98	901.934	900.97
St.deviation	0.1	0.26	0.224	0.14	18.688	16.727
Median	7	19	12	7	904.84	904.246
Min	7	18	11	6	850.387	850.387
Max	8	19	12	7	948.914	948.169
1st Quantile	7	19	12	7	892.972	892.886
3rd Quantile	7	19	12	7	912.817	911.724

Table 4.8: The business cycle indicators - descriptive statistics.

We can see from the statistical results presented in Table 4.8 that the count of the cycles during the run and its evolvement is quite stable. As the standard deviation in the count of cycles is zero, we can say that there were always seven full business cycles in the data from each simulation run. The period of a cycle, duration of its phases and amplitudes vary across cycles, but according to the standard deviations only slightly. The mean value of the period of a business cycle is around 19 macrosteps, where the mean value of the duration of the phase of expansion is 11.947 and of the contraction 6.98[29]. This is in line with the conclusions made from the statistical evaluation of confidence done in the first part of this Chapter. The mean value of the amount of optimists in the society was estimated bigger than the mean value of the amount of pessimists. The longer phases of the growth in the aggregate income and fast decrease in it was observed also in Figure 4.8 or Figure 4.9. The conclusion that the duration of an expansion in a business cycle is longer than the duration of a contraction is also one of the commonly accepted stylized facts about business cycle presented, for example, by Gabisch and Lorenz (1989).

We could be interested, why is this observed, especially in this simplified agent based model. The majority of model equations is symmetric. There are the same rules for the spread of an optimism and a pessimism, the same parameter for the sensitivity on the confidence in the neighborhood, on the change in the individual income, the same adjustment parameters for the individual consumption demand for the case of an optimist or a pessimist, the symmetric

[29]During the sensitivity analysis, we will find out that the period of the business cycle depends on parameter setting. Thus, it could be prolonged or shortened by changing their values. However, we can consider one macrostep as a quarter of a year and this cyclic movement as a medium-length type, with the average period 5 years.

adjustment of the marginal propensity to consume. The only difference and probably a possible explanation therefore could be in the definition of the upper and lower limitations, contributing to the turning points in the aggregate income. During the expansion, the production is reaching its potential output defined by the amount of workforce. During the contraction, some of the agents reach the lower limit for minimal individual consumption demand.

We can notice that the limitations are defined on different channels. During the expansion phase of the business cycle the production is limited. According to the results presented in Figure 4.14 and Figure 4.15 the production is after reaching its potential still remaining at this level, even though the aggregate demand is already decreasing (caused by the optimistic agents, who switch their marginal propensity to consume in favor to savings). From the equation (4.20) follows that the production is equal to the aggregate income. Thus, there is a period when the aggregate demand is already falling (which could be considered as a sign of future contraction in the aggregate income), but the aggregate income remains constant (because aggregate demand is still higher than the potential output of the firm). Thus, this period can be by the firm still perceived as the expansion and according to the definition is counted into the phase of expansion.

During the phase of a contraction, the limitation is related to the individual demand[30], therefore entering the aggregate demand immediately. As the production is not limited from below (except the case of nonnegative production, which is according to the simulation results presented, for example, in Figure 4.15 never the bounding restriction), it could flexibly react to the changes in the aggregate demand. However, according to the simulation results from production discussed before, the aggregate demand after reaching its limitation remains for some period on this level. The production is at the beginning of this period still falling, because the firm has big inventory. Once the firm is liberated from the excess of the inventory, it can start to increase the production, hence the aggregate income. This is the end of the contraction phase in the business cycle. The different situation for the firm in case of expansion and contraction could be the explanation for different duration of these phases.

It is worth mentioning that the cyclic movement with different duration for the expansion and the contraction could be observed also in the aggregate demand, but with the opposite characteristics. According to Figure 4.15 the phases of the growth in the aggregate demand seems to be shorter than the phases of its fall.

4.4.8 Sensitivity analysis

The analysis of sensitivity is provided mainly for two reasons. Firstly, we are interested in how sensitive is the cyclic behavior in the aggregate income, if we change the weight by the influence from the confidence in the agent's neighborhood (parameter $1 - \alpha^y$). By switching off this influence (setting $1 - \alpha^y = 0$ in (4.3)), the confidence of the agent will be determined by his/her expectations of the future incomes only. The individual demand for consumption spending

[30]According to definition of (4.15) each agent has some minimum demand for consumption, which he/she prefers in case of low income finance from his/her savings.

will be according to the equation (4.14) dependent only on the agent's consumption spending from the previous period, his/her expectation about his/her future stream of income and his/her adjustment in the marginal propensity to consume. Albeit, the confidence by the agents is still defined, we cannot consider this as a case of the spread of the optimism/pessimism in confidence among agents (there are no interactions anymore). This way we would like to evaluate the importance of the spread of optimism/pessimism in the agent's confidence for cyclical behavior in the aggregate income.

Finally, it is difficult to estimate the parameters which are entering the equations on the micro level if we do not use the micro data, especially for the confidence. We are interested how stable are the results while we are changing the values of model parameters. Hence, we did the sensitivity analysis for the model parameters α^y, α^{mpc}, γ and number of microsteps during confidence simulation T. During the sensitivity analysis, we always fix all parameters on their calibrated values and evaluate the sensitivity of results on the change in chosen parameter only. The change is observed in the net of 11 different values. The fixed values and the range of tested values for all parameters is presented in the Table 4.9.

	Parameter value during the sensitivity test			
	α^y	α^{mpc}	γ	T
Sensitivity on α^y	$0 \dots 1$	-0.15	0.55	1600
Sensitivity on α^{mpc}	0.5	$-0.4 \dots 0$	0.55	1600
Sensitivity on γ	0.5	-0.15	$0 \dots 1$	1600
Sensitivity on T	0.5	-0.15	0.55	$100 \dots 2500$

Table 4.9: Parameter setting for simulations.

The statistical evaluation of the results for each chosen parameter from the range was done in the same way as it was evaluated for the basic calibration, e.g. it was done on 1 model simulations for 300 macrosteps, the first 50 observations from each run were dropped. During the sensitivity analysis, we are mainly focused on the business cycle movement. We present the changes in the variables defined for evaluating the business cycle, e.g. the count of business cycles, its period, the duration of the phase of an expansion and a contraction and the amplitudes, following the same data adjustment, as in the basic setting. Further, we investigate the change in the aggregate income during various parameters setting.

The count of business cycles

Firstly, we are testing the sensitivity of cyclical behavior in the aggregate income on the choice of micro parameters. In Figure 4.20 there are boxplots of the count of cycles in the aggregate income in one run (*Count*) for different parameter setting. The red dot-and-dashed line in the graph correspond to the zero line, e.g. no full business cycle in the run.

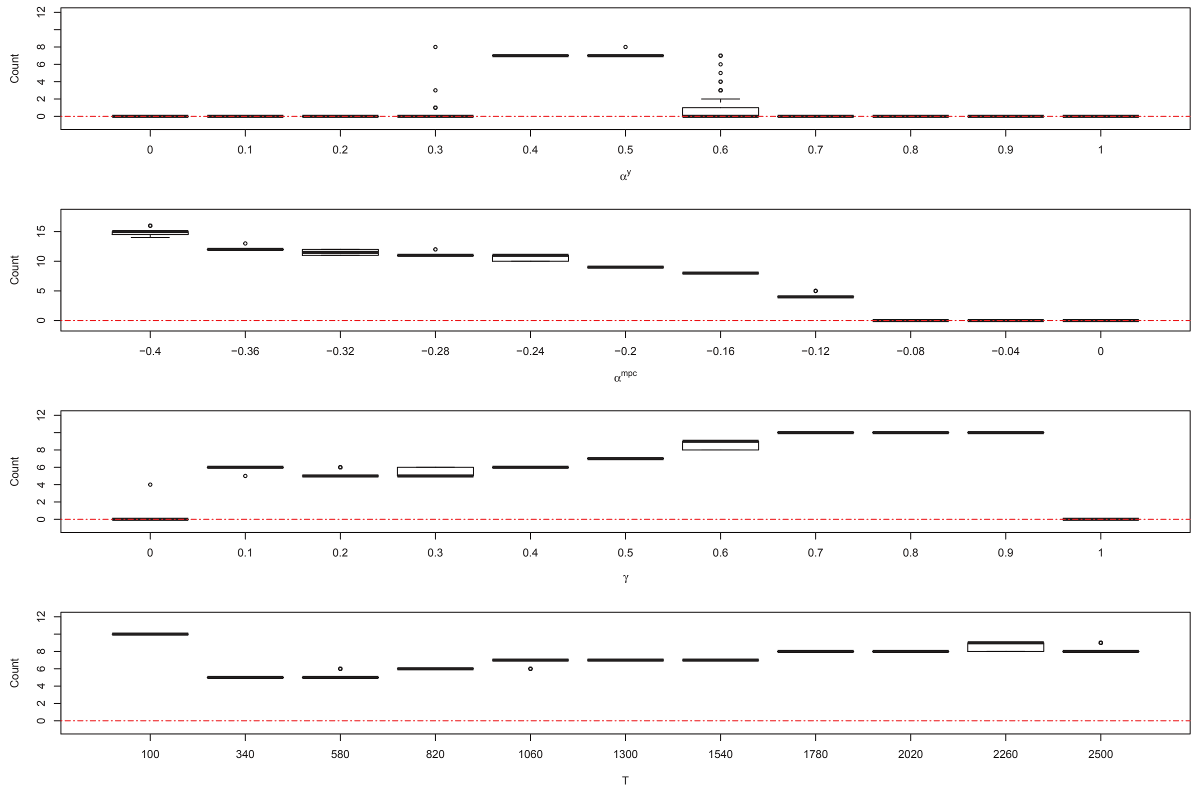

Figure 4.20: The count of cycles in one simulation run (*Count*) - boxplots.

According to the first graph in Figure 4.20 the cyclic behavior is very sensitive to the choice of parameter α^y. This parameter reflects the sensitivity of the consumer's confidence on his/her income, while $1 - \alpha^y$ the sensitivity on the confidence in his/her neighbourhood. The cyclic behavior was observed only for the α^y between 0.3 and 0.6 ceteris paribus (e.g. with all other model parameters and setting without the change). This means that, without considering the impact from the consumer's neighbourhood, there will be no cyclic movement. The main goal of this thesis was to investigate if the spread of optimism/pessimism in the consumer confidence could cause the cycle movement in the aggregate activity. These results confirm that if there will be no spread in the consumer confidence (meaning that there will be no influence from the neighbourhood and the consumer's confidence will purely depend on his/her income), there will be no cyclic movement ceteris paribus. However, if the impact of the consumer's neighbourhood on his/her confidence will be too high (α^y lower than 0.3), e.g. much higher than the impact of his/her income on it, the cyclic movement disappears too, ceteris paribus. Thus, we can conclude that the spread of the optimism/pessimism in consumer confidence causes the cyclical movement in the aggregate activity, if its influence on the consumer confidence, weighted by the parameter $1 - \alpha^y$, is between 0.4 and 0.7 ceteris paribus.

The zero count of the business cycles for other values of this parameter could mean that the aggregate income was stabilized on some value. The starting point of the simulations does not have to be and, is probably not, the steady state of this economy, which would lead to the development of the economy without fluctuations in the aggregate income. We are, during these simulations, dropping the first 50 observations to decrease the impact of the starting point on the simulation results. Thus, the aggregate income could, during these first observations, reach such steady state. The low values of α^y correspond to the high influence of the confidence from the agent's neighborhood and the very low influence of the agent's expectation about his/her future income. The low sensitivity to the changes in agent's income could, therefore, lead to the steady path of the economy. The high values of this parameter correspond to the increased sensitivity to the changes in agent's income and very low sensitivity on the confidence from the agent's neighborhood.

The parameter α^{mpc} represents the adjustment in the marginal propensity to consume. We can see from the second graph in Figure 4.20 that the bigger the adjustment (meant in the sense of the distance from zero - no adjustment), the higher count of business cycles. The greater changes in the marginal propensity to consume by consumers thus lead to the more cyclical development of the aggregate income. The results are in line with the expectations about this parameter. The optimistic consumers are after some periods decreasing their demand for consumption spending according to this adjustment parameter and vice versa, pessimistic consumers are after some periods increasing their demand for consumption according to this parameter. The high value of this adjustment has an negative influence on the aggregate demand during the phase of expansion and the positive effect on the aggregate demand during the phase of contraction. Thus, the turning points in the aggregate income seem to be achieved more quickly. For the values of α^{mpc} between -0.08 and 0 there was no cyclic behavior achieved, ceteris paribus. The range of this parameter between -0.08 and 0 means very low or no change in the marginal propensity to consume by consumers. Thus, we can conclude that flexible changes in their marginal propensity to consume could be an additional source of cyclic movement in the aggregate activity.

The count of business cycles seems to be sensitive also on the parameter γ, which is the parameter of the habit in the consumption spending. More precisely, this parameter expresses the weight by the last consumption in the determination of the agent's consumption demand, equation (4.15)) and thus also some level of flexibility in the individual demand for consumption spending with respect to the changes in individual income. For γ growing from the value 0.1 till 1 the count of business cycles are growing from 6 to 10 (presented in the third graph in Figure 4.20). It is an interesting observation and at the same time puzzling why with the growing level of rigidity in consumption demand the count of business cycles is actually increasing. The explanation of this will be provided later, while presenting the amplitude of the different phases of business cycles. For the extreme cases of γ (0 - no habit formation, and 1 - the consumption demand is equal to the last consumption spending) there was nearly or no cycle movement. The case of γ equal to 1 is straight forward - if the individual demand for consumption spending is always equal to the value of the consumption spending from the previous macrostep, there will be no fluctuations in the aggregate demand. The firm can adjust the production to follow this demand and the economy could reach the steady state.

In the fourth graph in Figure 4.20 the sensitivity on the number of microsteps is provided. This parameter determines the length of the simulation of the confidence spread between two macrosteps. We can see that with the growing number of microsteps (so more consumers are reconsidering their confidence between two macrosteps), the count of business cycles is growing. This is in line with the results achieved by Westerhoff (2010), who presented that this parameter actually determines the period of the business cycle. We can conclude that the higher amount of microsteps leads to faster spread of dominant confidence in the society, thus the faster achievement of the peaks in consumer confidence. We can think of the simulation result for 100 microsteps, which seems to be out of this pattern. The possible explanation for this could be that low number of microsteps could actually decrease the flexibility of the consumer confidence and thus its influence on the individual demand for consumption spending in favor to the previous consumption spending. This result will be then in line with the results achieved for the high values of habit, which were also connected with the high count of business cycles.

In sum, we can say, that the number of business cycles positively depends on agent's interactions and the influence of local information (low α^y), flexibility of the marginal propensity to consume (high α^{mpc}), number of microsteps (i.e. consumers reconsidering their confidence), as well as the importance of habit consumption (γ between 0 and 1).

The average period of business cycles

In addition, we have counted the average period of the business cycle during one run ($\phi Period$), the average duration of the expansion during the cycle and one run ($\phi Duration^E$) and the average duration of the contraction during the cycle and one run ($\phi Duration^C$) on the adjusted sample of data (first 50 observation dropped, only the data from full business cycle are taken). The boxplots of these variables for different parameter setting are presented in Figure 4.21 and Figure 4.22.

We can see from Figure 4.21 that the cyclical behavior is only for α^y between the values 0.3 and 0.6, the average period of the cycle is around 20 macrosteps[31] (the zero period of the business cycle and its phases correspond to the no cyclic movement in the aggregate income). These results are in line with the conclusion about the influence of the spread of optimism/pessimism in agent's confidence on the cyclic behavior in the aggregate income derived according to the results for the count of cycles above.

The average period of the cycle negatively depends on the flexibility of the marginal propensity to consume (controlled by the parameter α^{mpc}). With the lower flexibility (higher values of α^{mpc}), the average period of the business cycle during one run is longer. This is in line with the simulation results from the count of the business cycles in the run - for the higher values

[31]If we consider one macrostep as a one quarter of a year, the period of the cycle 20 macrosteps will correspond to 5 years, which is in line with the usual period of the middle size business cycles. As we can see from the simulation results, the period of the business cycle could be in case adjusted by the model parameters.

of α^{mpc} the average count of the business cycles was decreasing. The longer is the business cycle the less of them are in the simulation run. Low flexibility of the marginal propensity to consume corresponds, thus, to the less number of business cycles with the longer period. For α^{mpc} higher than -0.12 there is no cyclic movement.

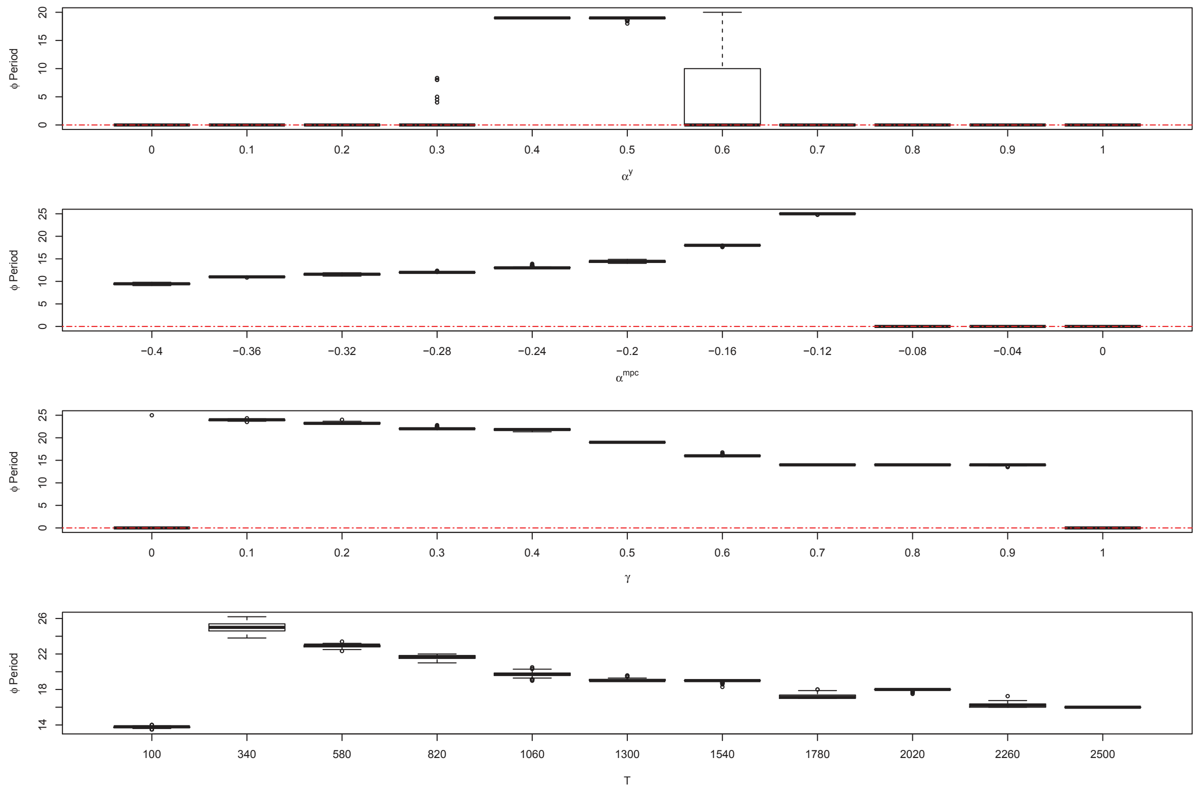

Figure 4.21: Average period of the business cycle.

The average period of the cycle also negatively depends on the importance of the habit formation, expressed by the parameter γ. With the increasing value of γ the period of the cycle decrease, from 25 to approximately 15 macrosteps. This corresponds to the previous results that with γ increasing the average count of business cycles during one simulation is increasing (there are more business cycles with smaller period). For extreme cases of γ (e.g. 0 and 1) there is no cyclic movement.

In addition, the average period of the business cycle negatively depends on the number of microsteps, i.e. the period of the simulation of the confidence spread among two macrosteps. The average period of the business cycle decreases from approximately 25 to 15 macrosteps while increasing number of microsteps. There is no business cycle movement in the case of 100 microsteps. The simulation results about the average period of the business cycle corresponds to the previous results obtained for the average count of the cycles. There is either high number of the short business cycles or lower number with longer business cycles.

We can see the analogous evolvement for the duration of phases of expansion and contraction in Figures 4.22. For the comparison, we present the boxplots for the duration of the phase of expansion during one run (green color) and the boxplots for the duration of the phase of contraction during one run (red color) in the same graph. We can see that the duration of expansion is always higher or equal to the duration of the contraction. The change of this difference seems to be sensitive to the importance of the habit formation (choice of parameter γ), the stronger the habit formation (the higher the parameter γ), the lower the difference. The duration of both phases of cycles is equal for γ higher or equal to 0.6.

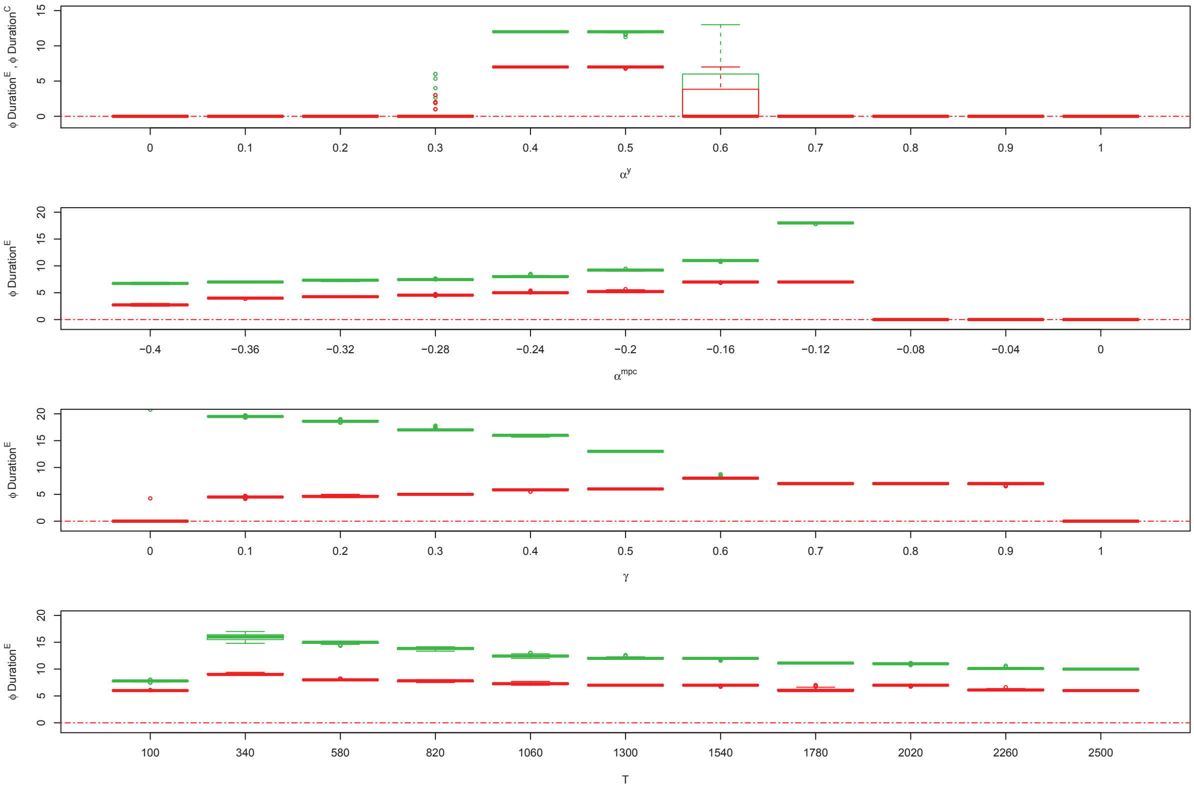

Figure 4.22: The average duration of the expansion and contraction phase in the business cycle.

The average income during business cycles

We count for each run a mean value of the aggregate income (ϕY)[32]. The boxplots of this variable for different parameter setting is presented in Figure 4.23. We can see that the aggregate income is lower and stable for values of α^y bellow 0.4 and higher and stable for values of α^y higher than 0.7. As we have already found out that by this setting there is no cyclic movement, these values correspond to the steady state values of aggregate income.

Parameter α^y influences the spread of confidence and determines the sensitivity of agent's confidence on the change in his/her individual income. We can see that in case of low sensitivity of agent's income on his/her confidence (the case when α^y is below 0.4), the average income is stabilized under the value 1000. It is exactly on the value of 960, which corresponds to the minimum aggregate demand based on the minimum level of consumption demanded by all agents. It seems that, with the low influence of the change in agent's income and

[32]The count is done from the data when first 50 observations were dropped.

thus, the high influence of his/her neighbourhood on his/her confidence, the pessimism spreads around the whole society and all agents start to demand their consumption minimum. In this case, the aggregate demand is set on this level. Once the aggregate demand is low, the firm is reducing its inventory until the production is stabilized to cover its target, which is according to the definition ((4.18)) equal to the double of the last realized sale, e.g. double of the minimum aggregate demand. The firm is producing this minimum aggregate demand and the same amount is held as an inventory buffer stock. Because the amount of production is equal to the aggregate income, the income of agents becomes constant. There is no change in individual income and the consumer expectation about future change in income ($Expincome_t^i$) is, according to the equation (4.2), equal to zero. If we look into the definition of the agent's confidence (4.4) we can see that the confidence is determined by the expected change in his/her income and the confidence in his/her neighbourhood. Once the change in his/her income is zero, the confidence of the agent is determined by the confidence in his/her neighbourhood only. Because the weight of the influence of the confidence in the agent's neighbourhood is equal to $1 - \alpha^y$, thus for α^y bellow 0.4 is very high and the majority of agents in the contraction are pessimists, it seems that for these values of α^y, the influence of the pessimism in the neighbourhood of the agent is too strong to change the confidence of an agent into the stable or optimistic state. Thus, all the agents remain pessimistic and their aggregate demand remains on its minimum level 960, as well as the aggregate income.

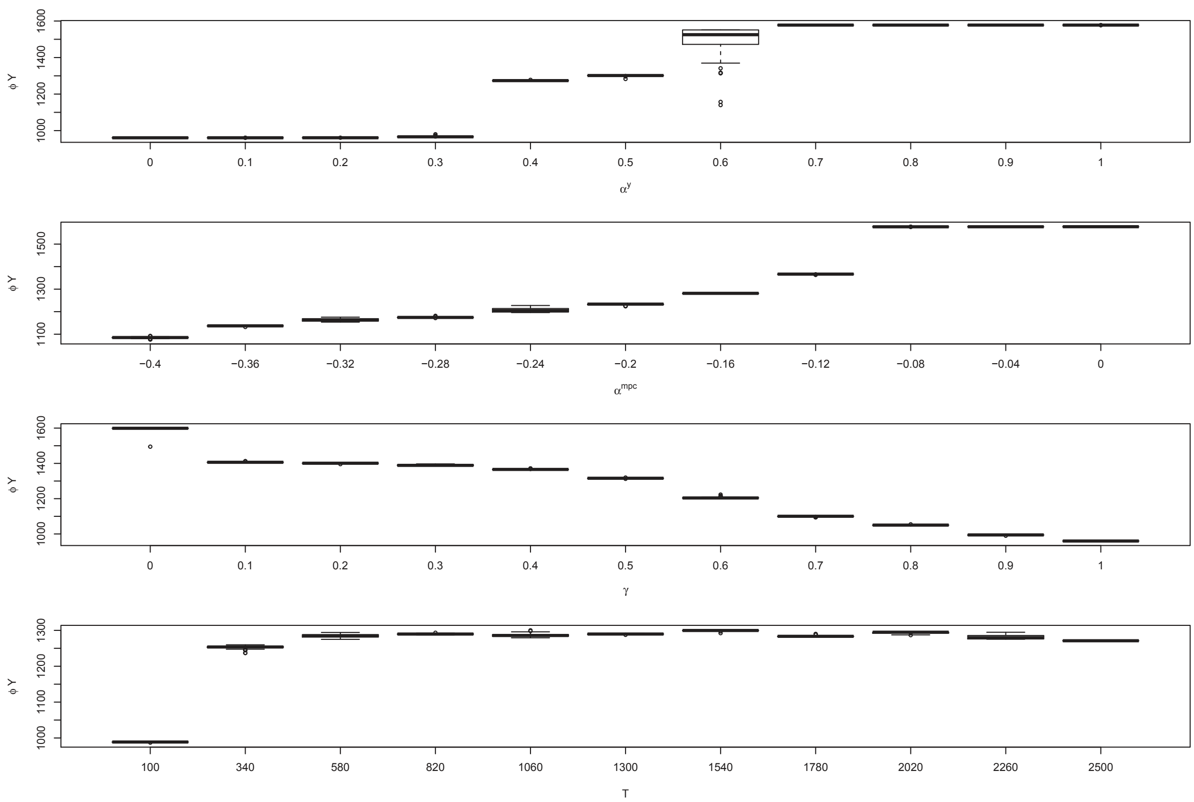

Figure 4.23: The average aggregate income during a run.

At the opposite extreme, when the value of α^y is higher than 0.7, the aggregate income is stabilized at the level 1600, which is equal to the maximum of the firm's production. This is the case, when agent's confidence is mainly influenced by his/her expectation about the change in his/her income and the influence of the neighbourhood is low. During the phase of expansion in the aggregate income, the firm reaches its production limit and the production, as well as aggregate income became, for some period, constant. This way, similarly to the previous case, the expected change in agent's income becomes zero. According to the definition of consumer's confidence (4.4) the confidence becomes dependent on the confidence in his/her neighbourhood only, however with the very low weight $1 - \alpha^y$. It seems that for the values of α^y higher than 0.7 the influence of the neighbourhood on agent's confidence is too small to change the agents' confidence into the pessimism or optimism and the agent will become stable. With such approach, the individual demand of an agent will be equal to its income. Thus, the aggregate demand will become equal to the aggregate income, i.e. the level of production. In this case, the firm is producing at its maximum level, keeping the inventory in the size of the aggregate demand (equal to production and the aggregate income) as a buffer stock. The aggregate income is stabilized at the level 1600.

According to the other simulation results presented in Figure 4.23, the average income during one run depends negatively on the flexibility of the marginal propensity to consume (with higher α^{mpc} the average income is increasing) and negatively on the importance of the habit formation in the consumption spending (the higher importance of the habit, i.e. higher the parameter γ, the lower the average income during one run). Except the case of 100 microsimulations, the average income is quite stable around the value 1300 with respect to the changes in parameter T.

The average amplitude of cyclical expansions and contractions

The last observed variable during sensitivity analysis is the amplitude in the aggregate income cycle. Firstly, the average value of the amplitude during the expansion phase ($\phi Amplitude^E$) and contraction phase ($\phi Amplitude^C$) within one run is counted[33]. The boxplots of these variables with respect to different parameter setting are presented in Figure 4.24. The red color presents the results for a contraction, the green one for an expansion.

As we can see, the results of both phases are nearly equal. This could be explained by the fact that there is a cyclical movement in the aggregate income, however, there is no growing or decreasing trend assumed. Thus, the average values of amplitudes, for both phases, have to be, according to their definitions, similar. The zero values for parameter α^y lower than 0.4 and higher than 0.6 are consistent with the previous conclusions that there is no cyclic movement by this setting. For other values and for the majority of the values tested for α^{mpc} and for T the average value of amplitude is quite stable slightly under the value 1000.

[33]The exact definition how the value is counted is described in the Chapter 5.4.7. The value is counted from the simulation data, where first 50 observations were dropped and further only the data covering the full business cycle were considered.

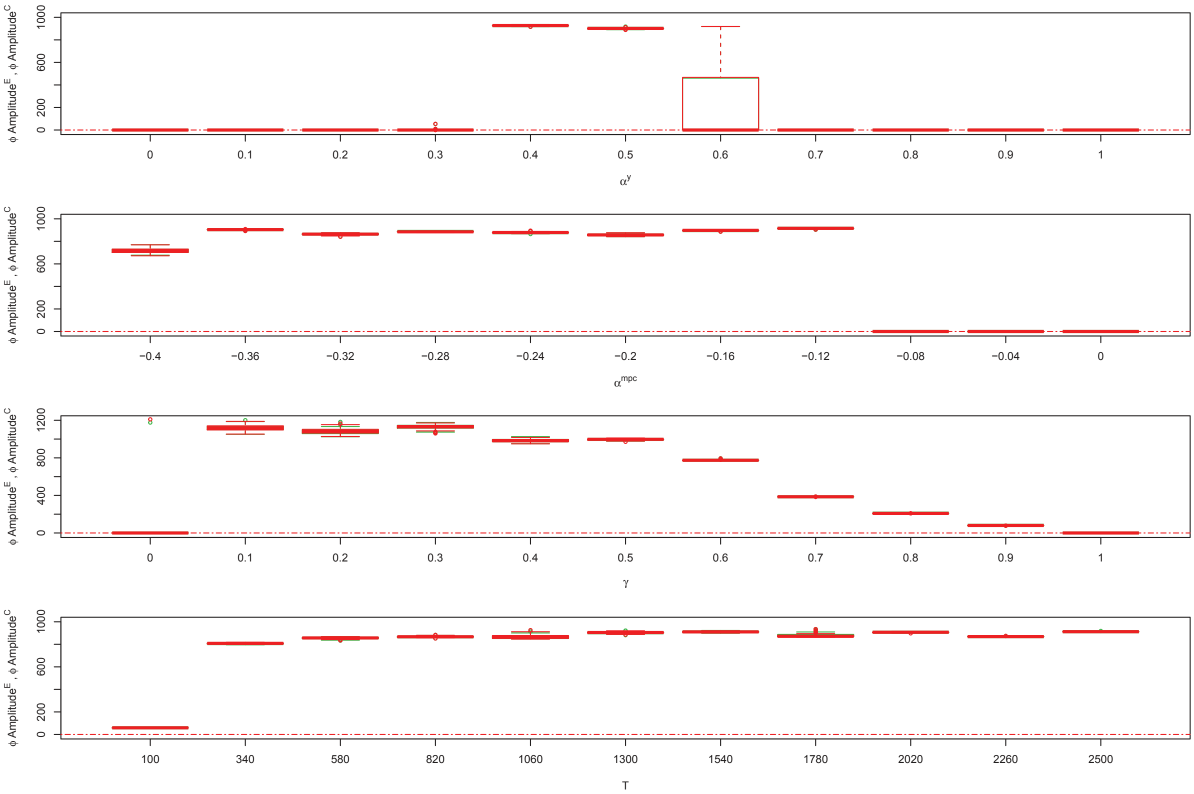

Figure 4.24: The average amplitude of the expansion and the contraction phase in the aggregate income cycle.

According to the simulation results the average amplitude depends negatively on the importance of the habit formation in the agent's consumption demand (represented by the parameter γ). With the growing importance of the habit in the consumption spending, the average amplitude is decreasing from the value around 1200 ($\gamma = 0.1$) to value around 100 ($\gamma = 0.9$)). This is quite an interesting result. From the previous results we found out that with the increase of flexibility in the consumption spending (e.g. decrease of γ) the count of business cycle is decreasing. However, according to the statistical evaluations of amplitude we can conclude, that this does not mean a lessening of the business cycle movement. Actually, it means that the cyclic movement in the aggregate income is slower, however, with the deeper swings up and down. Less important habit behavior thus leads to a lower number of business cycles which are, however, of a greater magnitude. With higher values of γ the cyclic movement is more frequent but smoother, thus probably less costly for the economy. Higher level of rigidness seems to be contributing to stabilizing the fluctuations in the aggregate income.

5 The ACE model with a heterogeneous labor market

The extended version of an ACE model was also programmed in software R[34]. The model was extended for a heterogeneous labor market to control for the impact of unemployment on the consumer confidence.[35] During simulation of this model the cyclical development of economic activity was observed. The first version of the extended model with a heterogeneous labor market was used, also, to measure the consumption-income ratio (Závacká, 2015b) and the income inequality during the business cycle (Závacká, 2015c). The list of all model variables could be found in Appendix A.1, the list of equations in the extended model in Appendix A.3.

5.1 The macroeconomic part of the model

According to Mueller (1966) and Malley and Moutos (1996), the consumer confidence is strongly influenced by the rate of unemployment. Hence, we have extended the baseline model for the heterogeneous labor market and unemployed agents. We have also added into the model a fiscal authority in the form of social fund to redistribute the income and provide the minimal financial help to the unemployed. This social fund is financed from the share of wages of employed consumers.

The scheme of this extended version of the model is presented in Figure 5.1. The confidence of agents is expressed by the color (the green color for optimists, the red color for pessimists and the black color for stable agents). The agent with the ability to work as a 1st-tier worker is marked with the circle shape, the agent with the ability to work as a 2nd-tier worker with the square shape. The empty circle or square assign that the agent is unemployed at this time, whereas the full colored shape means that the agent is working.

For this extension of the model the behavior of the firm and some other equations had to be adjusted. All the changes which were done are introduced below. The definition of consumer confidence together with the simulation mechanism remained unchanged.

[34]The code of the extended model is attached in CD.

[35]The consumer confidence could be also strongly influenced by the hyperinflation, price bubbles on the real estate market or exogennous shocks. However, we work, in the model, with the stable price level, so we leave these potential influences on confidence for future investigations.

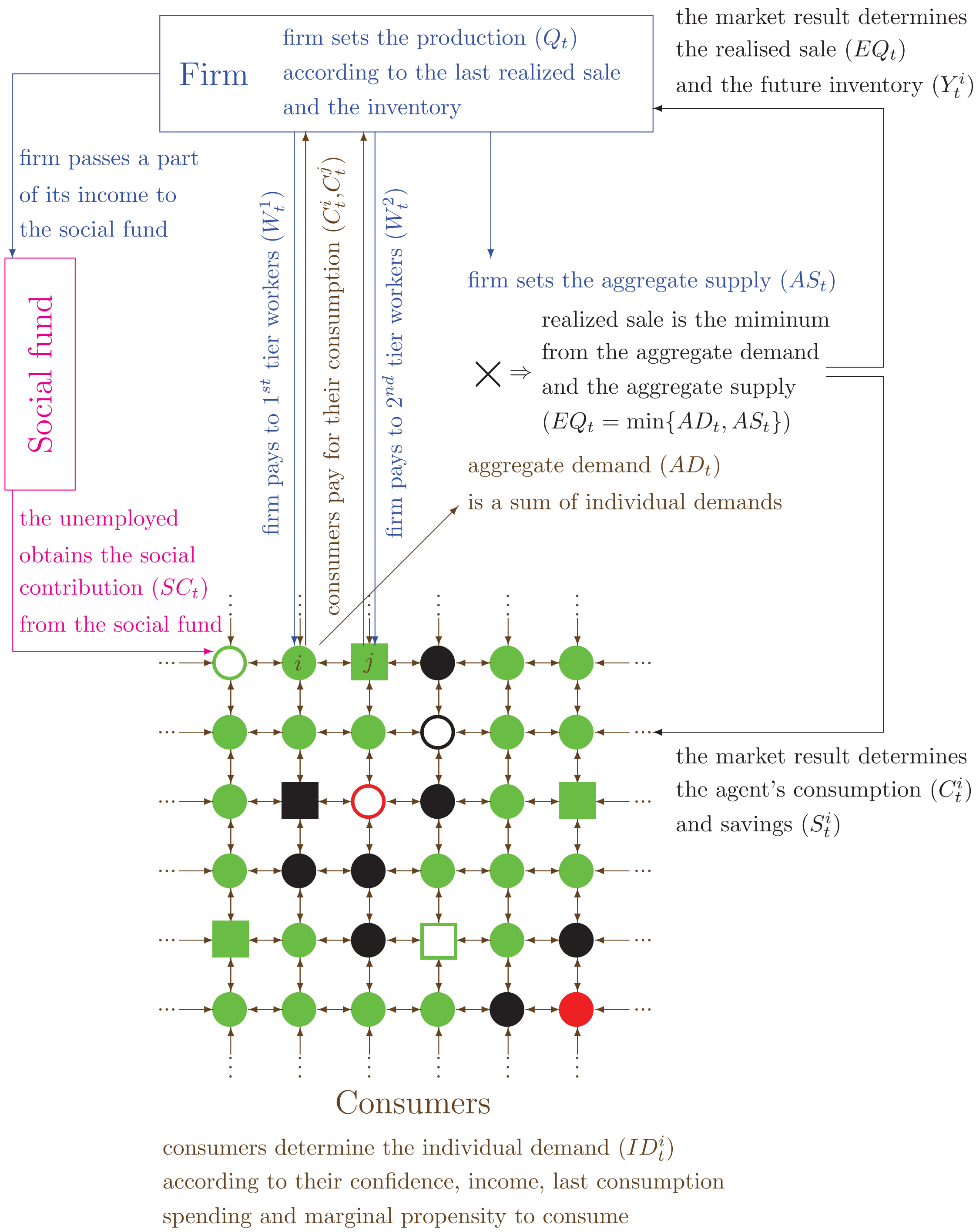

Figure 5.1: The scheme of the extended model.

5.1.1 Labor market

In order to respect the role of income on the consumer confidence, we have built a heterogeneous labor market following the structure of Ciarli et al. (2010). The agents are heterogenneous in their labor, as well as in their incomes. We distinguish among two types of workers and unemployed. The 1st-tier workers L^1_{t+1} directly participate on production[36]. The 2nd-tier workers L^2_{t+2} could be understood as managers. For each ν 1st-tier worker there is a need of one 2nd-tier worker. Hence, the amount of 2nd-tier workers is defined as

$$L^2_{t+1} = \frac{1}{\nu} L^1_{t+1}. \tag{5.1}$$

The total amount of workers L_{t+1} is

$$L_{t+1} = L^1_{t+1} + L^2_{t+1} = L^1_{t+1}\left(1 + \frac{1}{\nu}\right). \tag{5.2}$$

All agents, which are not part of these working groups, are unemployed. As there are in total M agents in the model (the amount of agents is constant over time), the number of unemployed U_{t+1} in time $t+1$ is

$$U_{t+1} = M - L_{t+1}. \tag{5.3}$$

We are not considering learning in the model. The full employment in the model is considered as maximal multiple of $(1 + \frac{1}{\nu})$, which is an integer and is lower than M. According to this full employment and the proportional distribution among 1st-tier and 2nd-tier workers, there is a labor lottery among agents. Each agent is randomly assigned to have an ability to work as a 1st-tier worker, 2nd-tier worker or to be an unemployed agent. This ability does not change during the time.

Further, we are not measuring the labor in the number of working hours anymore. We prefer to measure the labor in the amount of workers. By this setting, we are able to simulate the impact of the loss of the agent's job on his/her confidence and consumption demand through the decrease in his/her income. This was not possible in the baseline model with homogenous labor market. The decrease of the labor in the extended version of the model is, thus, expressed by the increase of unemployed agents.

Firm

According to the new workforce structure the equations of firm production have to be adjusted. The definition about the market environment together with the strategy of the firm remained unchanged. Following Ciarli et al. (2010), we define the production function as a function

[36]We use the definition of model variables for the macrostep $t+1$ in line with the definitions in the baseline model and in the code of the model.

of the 1st-tier workers only[37]. The equation (4.19) is defined by different labor definition as

$$Q_{t+1} = a^L L^1_{t+1} = \frac{\nu}{1+\nu} a^L L_{t+1}. \tag{5.4}$$

The demand for the workforce of tier 1 $\bar{L}^1_{t+1}$ is then

$$\bar{L}^1_{t+1} = \frac{\bar{Q}_{t+1}}{a^L}. \tag{5.5}$$

The equation about the desired level of production (4.18) remains.

The rigidity of the labor market is, in the model, expressed in two ways. Firstly, the target production is already defined according to the last market result. Thus, the evolvement of the production is rather smooth. Secondly, we are always taking the nearest lower integers for the amount of 1st-tier and 2nd-tier workers, which correspond with the constant share of 1st-tier workers per one 2nd-tier worker and could cover the most of this demand. This way, the amount of both tier workers is the integers (the count of workers) and the amount of newly hired workers is always equal to the demanded one or lower.

In case the firm is willing to increase the number of labor force, the labor force is randomly chosen from the unemployed agents with the desired ability[38]. By analogy, the reduction of the labor force is done by random choice of already employed agents with the proper ability. We do not have to consider the upper limitation of the amount of workforce (the total number of agents, e.g. M), because this constraint is already applied by determination of the target level of production. The final workforce of 2nd-tier workers L^2_{t+1} at time t is defined

$$L^2_{t+1} = \left\lfloor \frac{\bar{L}^1_{t+1}}{\nu} \right\rfloor, \tag{5.6}$$

where $\lfloor\rfloor$ assign the nearest lower integer of the number. The final workforce of 1st-tier workers L^1_{t+1} at time $t+1$ is then determined by the equation (5.1) and total amount of workers L_{t+1} at time $t+1$ by the equation (5.2). Further, we derive the final realized production Q_{t+1} (from equation (5.4)) and the aggregate supply (from the equation (4.17)).

As is the case of baseline model, because of the zero profit of the firm and the price normalized to 1, the value of produced good is equal to its production costs. The firm is paying to all workers for their production and contribute to the social fund, which is used

[37]The production also depends on the 2nd-tier workers, however, they are understood in the model as "managers", thus, not producing directly the good but rather organizing the 1st-tier workers and improving their marginal product of labor. in the model, the share of managers per 1st-tier workers is always kept constant. Thus, their contribution in the production is expressed within the marginal product of labor of the 1st-tier worker and is constant in time.

[38]The 1st-tier workers are chosen from the unemployed agents with the ability to work as 1st-tier workers, the 2nd-tier workers from the unemployed agents with the ability to work as the 2nd-tier workers. According to the model setting, this ability remains constant over time. Thus, an agent with the ability of the 1st-tier worker could be always employed as a 1st-tier worker only or be unemployed, an agent with the ability of the 2nd-tier worker could be always employed as a 2nd-tier worker or be unemployed.

for the payments to the unemployed agents. Thus, the value of production is directly equal to the aggregate income Y_{t+1}. Hence the equation (4.20) from the baseline model remains the same, also for the extended version.

5.1.2 Wages and unemployment

The wage structure in the model is defined similarly to Ciarli et al. (2010) and corresponds to the labor market structure. 1st-tier workers obtain for their work a wage W^1_{t+1}. 2nd-tier workers obtain their wage W^2_{t+1}, which is equal to multiple b of the wage of 1st-tier workers.

$$W^2_{t+1} = bW^1_{t+1+1}. \tag{5.7}$$

An unemployed agent obtains a social contribution SC_{t+1} from the social fund financed by the firm. The social contribution SC_{t+1} is defined as a share ω^U of the wage of 1st-tier workers, e.g.

$$SC_{t+1} = \omega^U W^1_{t+1}. \tag{5.8}$$

Hence the personal income of each agent i is equal to

$$Y^i_{t+1} = \begin{cases} W^1_{t+1} & \text{for the 1st-tier workers,} \\ W^2_{t+1} & \text{for the 2nd-tier workers,} \\ SC_{t+1} & \text{for the unemployed.} \end{cases} \tag{5.9}$$

The social fund serves for the redistribution of the aggregate income among employed and unemployed agents and its size fluctuates with the business cycle. This fund is in each period balanced (e.g. the revenues into the social fund obtained from the firm are equal to the expenses paid to the unemployed)[39] The aggregate income is redistributed among all agents, e.g.

$$Y_{t+1} = L^1_{t+1}W^1_{t+1} + L^2_{t+1}W^2_{t+1} + U_{t+1}SC_{t+1}. \tag{5.10}$$

This implies that the wage of 1st-tier worker is equal to

$$W^1_{t+1} = \frac{Y_{t+1}}{\omega^U U_{t+1} + L^1_{t+1} + bL^2_{t+1}}. \tag{5.11}$$

The determination of the wage W^1_{t+1} further determines the wage W^2_{t+1} (from the equation (5.7)) and the social contribution SC_{t+1} (from the equation (5.8)). All other model equations remain unchanged.

[39]This is a system of redistribution. The aggregate income, which is paid by the firm, would be paid to the workers only. Thus, the part of this income is taken and paid into the unemployed by the social fund. The amount of income paid to the workers is reduced for the amount of expenses for social contributions.

5.2 Model calibration

We have decided to keep, in the extended version of the model, the structure of the lattice and parameters equal to the case of the baseline model. The only exception was done for the parameter a^L. This parameter stands for the marginal productivity of labor. In the baseline model, the production function was a function of the amount of labor provided by all agents. The parameter is set $a^L = 1$. This way, the full employment, when all agents provide exactly one unit of labor, is equal to M. In this case, the production during the full employment is equal to M also.

In the extended version of the model, the production function is a function of the number of 1st-tier workers (defined in (5.4)). The contribution of the 2nd-tier workers to the production is expressed through the increase of the marginal productivity of labor of the 1st-tier workers, which is kept constant over time. The full employment is defined as the situation, when all the agents with the ability to work as a 1st-tier worker are working. Because of the structure of the labor market, there is in M agents four agents with the "ability" to be unemployed[40]. Thus, the marginal productivity of 1st-tier worker is calibrated to $a^L \doteq 1.203$, ensuring that the production during the full employment is equal to M as well. Once the majority of the parameters in the models is equal, we are motivated to set even the maximum level of production in the baseline and the extended model to be equal in order to compare the model results. The new parameters for the labor market b and ν were calibrated according to Ciarli et al. (2010). All values of parameters used in the model can be found in Table 5.1, the starting point setting in Table 5.2 (all values rounded to three decimal points).

To keep some level of consistency, the starting point was, for this time, set as the case of full employment and the maximal level of production (1600). From this setting, the aggregate income and its redistribution are determined. The amount of inventory was set 1600 too, to be in line with the production target definition. The amount of assets of consumers is equal to the value of inventory of the firm. The expectation about the future growth of income was set to 0 for all agents, as well as the adjustment for the marginal propensity to consume. The confidence was set in the way that half of the society are stable agents and the second half pessimists (the situation which is already in the phase of decrease in the aggregate income). The consumption demand ID_1^i of an agent i at the macrostep 1 (starting point) was defined as

$$ID_1^i = \begin{cases} (1+x)Y_1^i & \text{optimist,} \\ Y_1^i & \text{stable agent,} \\ (1-x)Y_1^i & \text{pessimist.} \end{cases} \tag{5.12}$$

This further determines the aggregate demand, savings, assets and inventory at macrostep 1.

[40]These agents are unemployed all the time, even during the full employment.

Parameter	Description
$M = 1600$	Number of consumers
$T = 1600$	Number of microsteps
$TT = 300$	Number of macrosteps
$x = 0.1$	Extrapolation parameter
$\alpha^y = 0.5$	Income sensitivity parameter
$\alpha^{mpc} = -0.15$	Consumption sensitivity parameter
$\gamma = 0.55$	Habit parameter by consumption
$C^0 = 0.6$	Minimal consumption parameter
$a^L \doteq 1.203$	Labor productivity parameter
$b = 2$	Tier multiplier
$\nu = 5$	Executive wage multiplier
$\omega^U = 0.6$	Social contribution parameter

Table 5.1: Parameter setting in the extended model.

$O_1 = 0$	$AD_1 = 1519.691$	$C_1 = 1519.691$	$L_1 = 1596$	$U_1 = 4$	$SC_t = 0.515$
$ST_1 = 800$	$AS_1 = 3200$	$S_1 = 80.309$	$Q_1 = 1600$	$L_1^1 = 1330$	$W_1^1 = 0.858$
$P_1 = 800$	$EQ_1 = 1519.691$	$A_1 = 1600$	$Y_1 = 1600$	$L_1^2 = 266$	$W_1^2 = 1.716$
$Expincome_1^i = 0$	$\Delta mpc_1^i = 0$	$I_1 = 1600$			

Table 5.2: Starting point setting - extended model.

The validation of the simulation results was done on the business cycle stylized facts (SF1)-(SF9) defined in the baseline version already.

5.3 Simulation results

As in the baseline model, we will focus, during the analysis of the simulation results, on the influence of the spread of optimism/pessimism in agent's confidence on the aggregate demand and further on the aggregate income. To support the validation of the model the development of the main macroeconomic variables will be investigated too. In accordance with the baseline version of the model, we would like to present the simulation results on the one run of the model for 300 macrosteps and further the statistical evaluation for 150 macrosteps (driven for 100 runs, each of 200 macrosteps with the drop of first 50 observations). The graphical presentation is equal to the baseline case, too, e.g. the solid line represents the mean value of the variable and dashed lines the minimum and the maximum at the macrostep. Other statistical indicators are presented in the tables (values are rounded to three decimal points). At the end of this subsection, the analysis of sensitivity for various parameters is provided.

5.3.1 The spread of the consumer confidence

The spread of the waves of optimism and pessimism on the lattice can be seen in Figure 5.2. As in the case of baseline model, we are showing the spread between the macrosteps 181 and

196 with the step of the length one, the optimistic agents are depicted by the green color, the stable ones with the black color and pessimistic agents with the red color. We can see that the spread is following the same pattern as in the baseline model. In macrostep 181 there is a majority of optimistic agents in the society, with some of the agents which are pessimists. In macrostep 183 the optimistic wave in confidence seems to disappear, the confidence in the society is mixed. The wave of pessimism in the confidence starts in macrostep 184, reaching its peak around macrostep 188. Then, the confidence turns back into the optimistic wave anew (starting in macrostep 190). After that, we can see the slow change in the confidence of agents into the optimism. Even from this short extract of simulation, we can see that the optimistic wave seems to be longer than the pessimistic one.

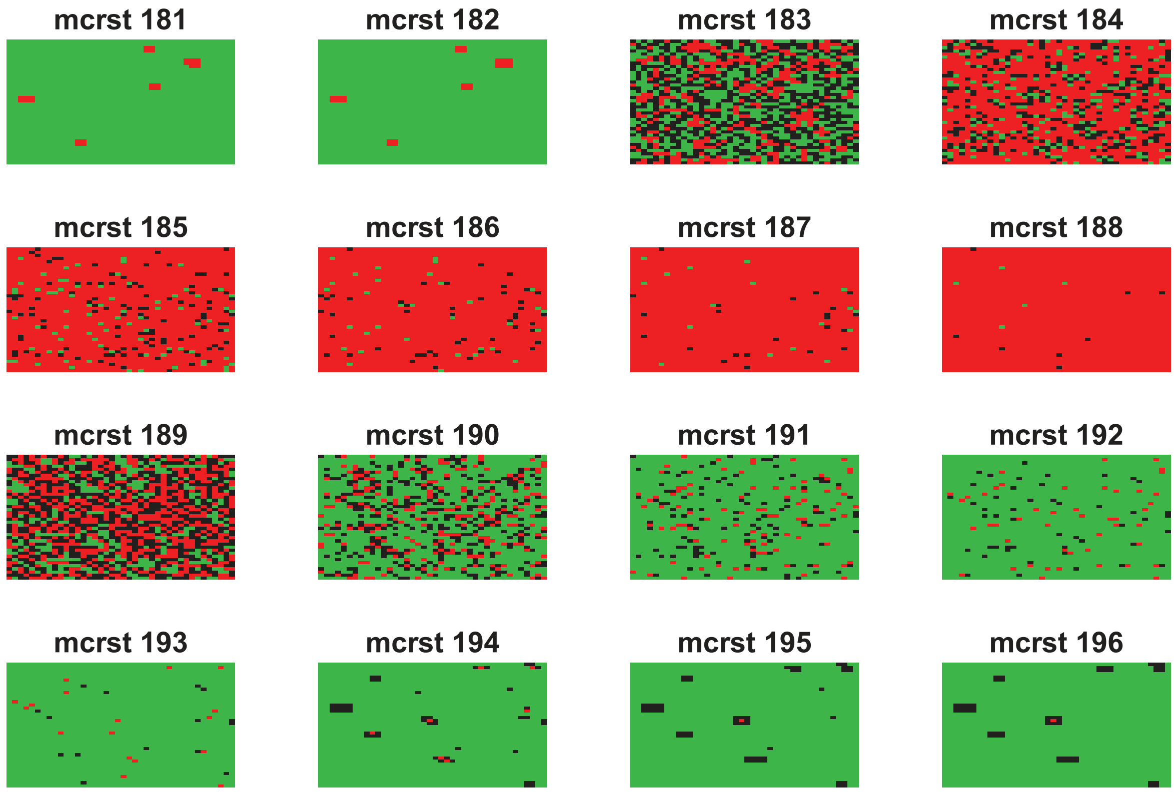

Figure 5.2: The optimists, stable ones and pessimists in the lattice.

The consumer confidence in the aggregated form during one run is presented in Figure 5.3. The green line represents the total amount of optimists in the lattice, the black line the total amount of stable agents and the red line the total amount of pessimists in the lattice. As in the baseline case, we can see how the waves of optimism slowly turn into the waves of pessimism, and that the amount of stable agents increase during these changes. The phases with the majority of optimistic agents in the society are much longer that the phases with the prevailing pessimistic confidence.

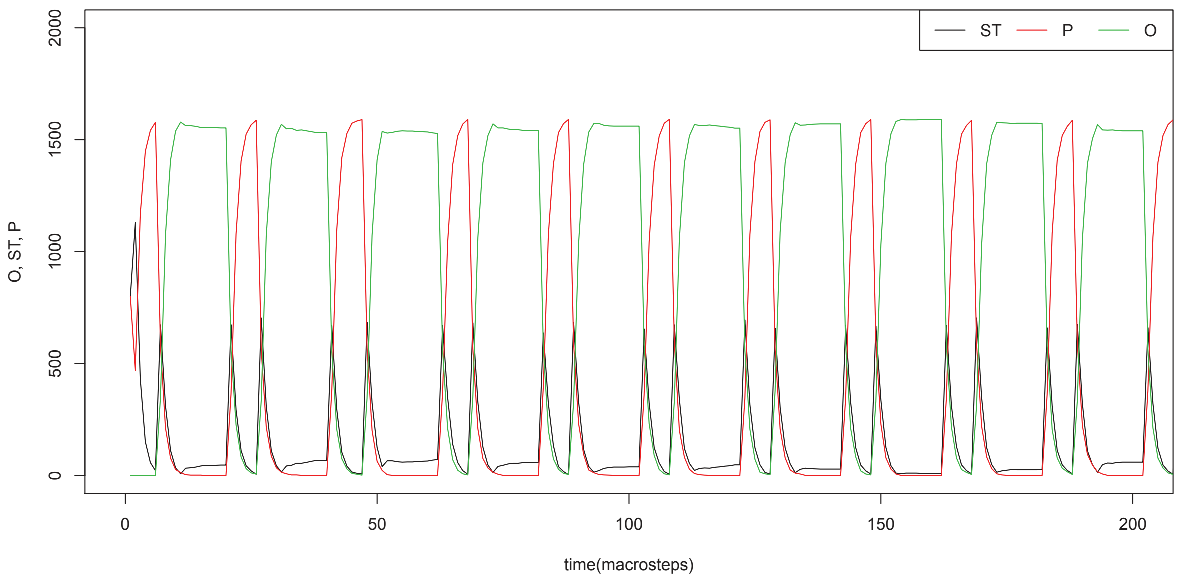

Figure 5.3: The amount of optimists (O), stable agents (ST) and pessimists (P) during one run.

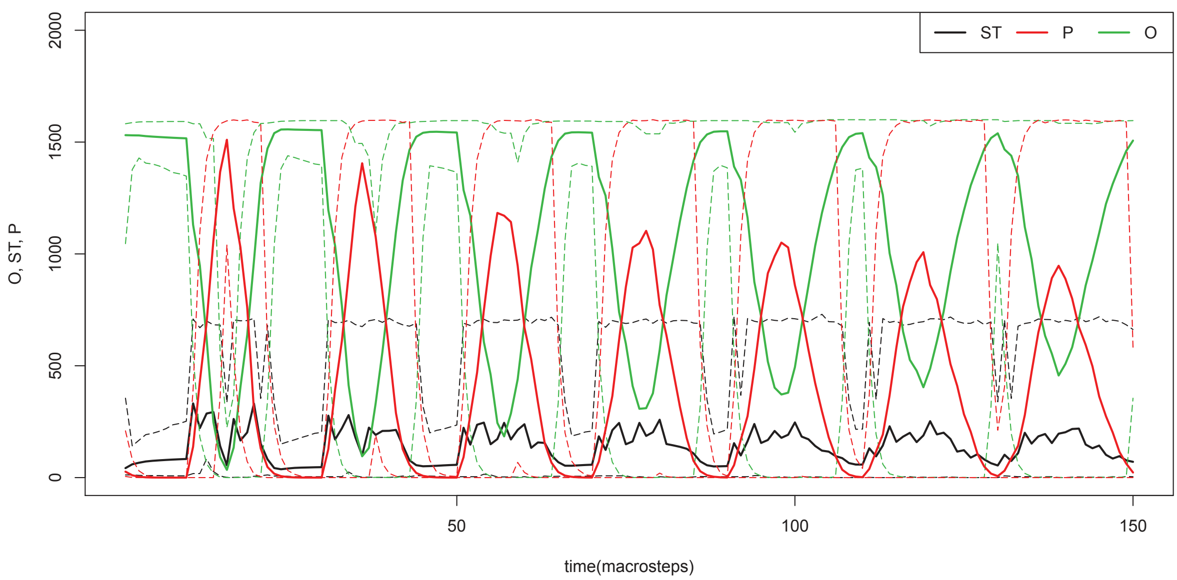

Figure 5.4: The amount of optimists (O), stable agents (ST) and pessimists (P) - statistical evaluation.

The statistical evaluation of the aggregated confidence in the society is presented in Figure 5.4 and Table 5.3. The first impression from the evolvement of the mean value of the total amount of pessimists and optimists in the society could be that the total amount of the pessimists in the society is with the time decreasing. However, we cannot see this tendency in Figure 5.3 with simulation results from one run. We can observe that the peak of the mean value of the count of pessimists in the society is decreasing, however the waves in this development are lengthening. The same situation is valid for the bottoms of the mean value of optimists. This development is the effect of the randomness in the cycle movement. All simulations have the same starting point, thus the timing of the first downturns and upturns in agents' confidence is nearly the same. With increasing number of macrosteps, the timing of the peaks and bottoms in the amount of optimists/stable agents/pessimists differ and lead to higher spread of minimum and maximum values around the mean values of observed variables. The decreasing tendency of the mean value of the total amount of pessimists is caused by this nonsynchronized timing (in some runs the amount of pessimists is already at its peak, but in others it could be opposite). The similar decreasing tendency could be also observed in the mean value of the amount of optimists and stable agents, however, the decrease is slower.

Statistics	O	P	ST	$CONF$
Mean	1048.39	411.563	140.047	636.827
Standard deviation	645.966	607.953	192.654	1239.613
Median	1482	12	50	1477
Min	0	0	0	−1600
Max	1600	1600	730	1600
1st Quantile	318	0	25	−276
3rd Quantile	1561	599	134	1558

Table 5.3: The amount of optimists (O), stable agents (ST), pessimists (P) and the indicator of confidence ($CONF$) - descriptive statistics.

According to the statistical results presented in Table 5.3 the mean value of the amount of optimists during the cycle is higher than the mean value of the amount of pessimists. This is in accordance with the simulation results from the one run (Figure 5.3), where the optimistic waves are longer than the pessimistic ones. Both variables are achieving the minimal value zero and the maximum value 1600 (all agents).

5.3.2 The aggregate demand

As in the baseline case, we are interested if the spread of the optimism/pessimism in the confidence of agents could lead to the cyclic movement in the aggregate demand. The simulation results from one run and the mean values of these variables with their minimum and maximum values are presented in Figure 5.5 and Figure 5.6. We can see the very similar pattern as in the baseline version of the model. In the simulation from one run (in Figure 5.5) the confidence indicator $CONF$ is a leading variable for the aggregate demand. The upper turning points of both variables seem to happen in the same macrosteps and the downturn of the confidence indicator seems to be leading the downturn in the aggregate demand.

The explanation of this behavior is the same as in the baseline model. The growth in the aggregate demand is, before reaching its peak, slowing down because of the change in the marginal propensity to consume by optimistic agents, while the indicator of confidence is still growing thanks to the spread of optimism among agents. After reaching their peaks, the fall is first observed in the aggregate demand (caused by the higher preference for postponed, rather than immediate consumption). The fall in the indicator of consumer confidence is following later, when the fall in the aggregate demand causes the fall in the firm's production (according to the firm's target production setting) and thus, the fall in agents' incomes.

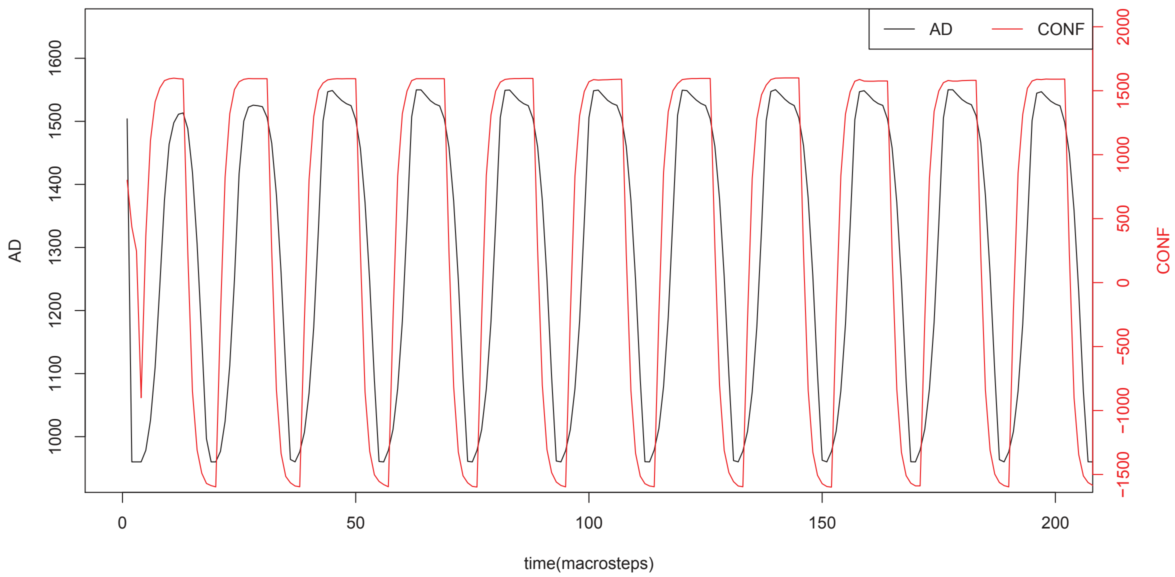

Figure 5.5: The consumer confidence indicator versus aggregate income.

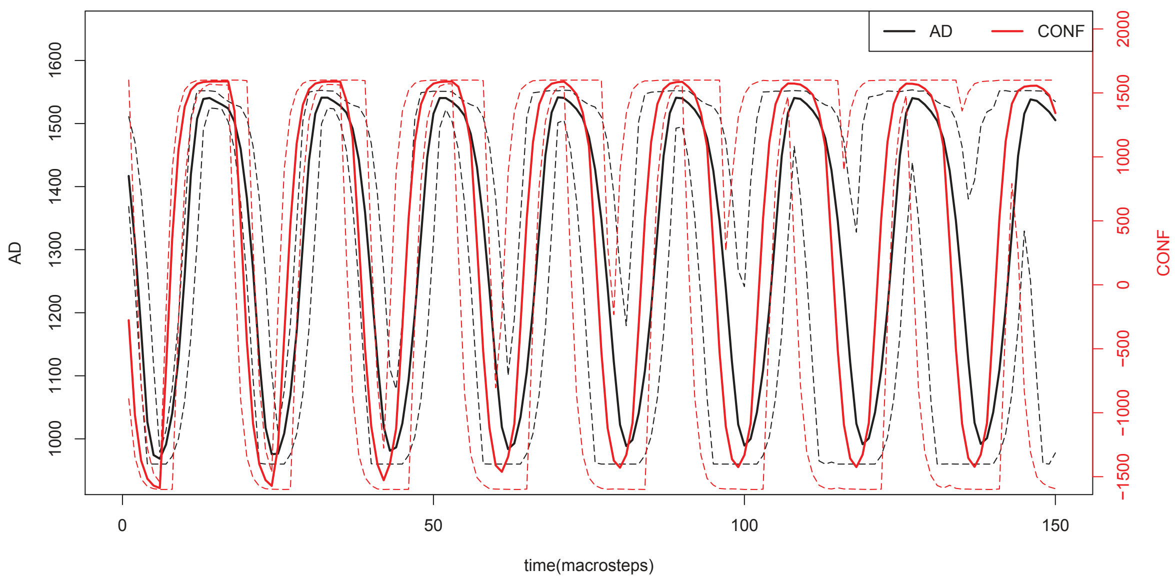

Figure 5.6: The consumer confidence indicator versus aggregate income - statistical evaluation.

After the period of contraction in both variables, the switch into the growth is first observed in the aggregate demand. As was already explained for the baseline version, it is a period when the firm decreases its inventory enough to increase its production again. With the increase of the production the agents' incomes and thus imediately their consumption demand is increased.

However, because of the high amount of pessimists in agents' neighbourhoods the growth in the indicator of confidence starts later.

The mean values of these variables (in Figure 5.6) are in line with these conclusions, this time however the consumer confidence indicator seems to be leading even in turning points of both variables. These results do not reject the hypothesis that the optimistic or pessimistic fluctuations in the confidence could lead to the cyclic behavior in the aggregate demand, both variables seem to be closely connected.

5.3.3 The aggregate income

The development of the aggregate activity together with the aggregate demand and aggregate supply during one run is presented in Figure 5.7. Again, we can observe the cyclical movement of all variables. In addition, it seems that evolvement of these variables follow some regular pattern. As we have already explained, in the baseline model, the propagation mechanism of the cyclic movement in the aggregate activity and on the simulation results the comovement of other variables, the repeating pattern is not surprising.

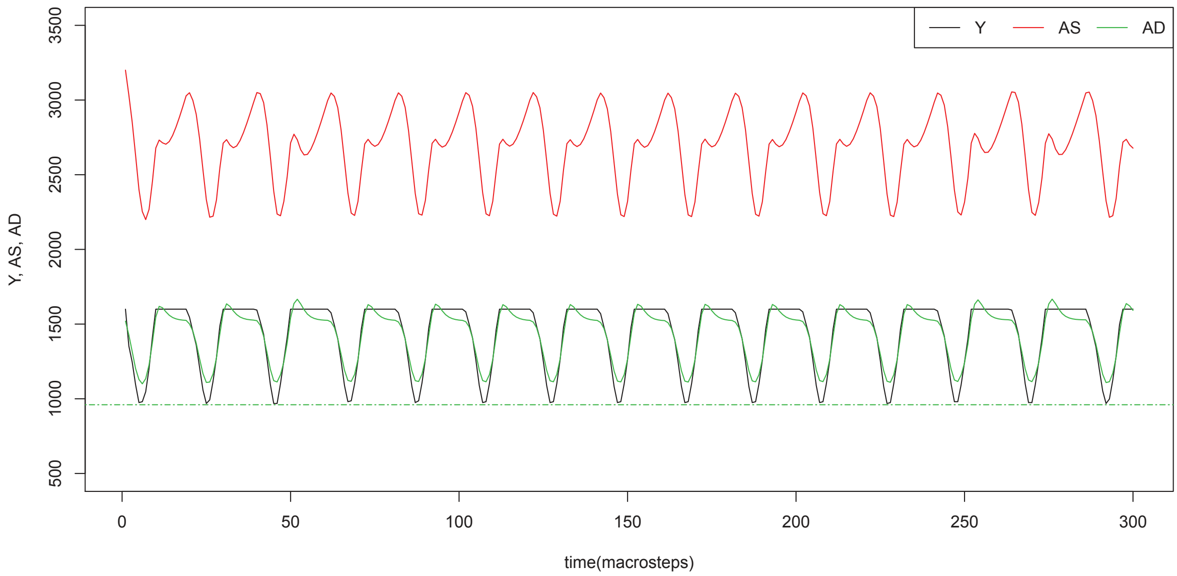

Figure 5.7: Aggregate income (Y), aggregate supply (AS) and aggregate demand (AD) during one run.

We could consider if there should be more obvious random movement observed in the data, however, we believe that it should not. The strong random movement in the simulation results is usually caused by the model variables, which are defined as random walk processes (the example of such variable could be the technological process) or by simulations with external random shocks. As we do not have such variables in the model (firstly, there was no reason to use them, secondly, there would be a reason to use it for the technological progress, but this is, for the sake of simplicity, not considered in the model at all), the random evolvement is not so obvious. However, the random behavior is occurring in more parts of the model. Firstly, during the simulation of the spread of consumer confidence there is always, in the each microstep, a random choice of an agent, who is going to reconsider his/her state of confidence. Thus, the spread of consumer confidence is always random. Secondly, in the extended model, the increase and the decrease of the labor force is always done by lottery. Lastly, there is a lottery for the working ability of each agent at the beginning of each simulation. Thus, as we can see, the pattern in the evolvement of model variables seems to be repeating, however not exactly.

The aggregate income is, during the upper turning points, reaching its maximum 1600, which is equal to the production generated with the full employment. The lower limitation of the aggregate demand (green dot-and dashed-line in the graph), set by the minimum level of consumption spending by all agents, is not reached. The aggregate demand nearly coincides with the aggregate income, the major difference among these series is during their turning points. As the aggregate income is limited from up, after reaching its maximum, is remaining at this level for some period. The aggregate demand continues to grow and after reaching its peak starts to fall immediately. The first fall is caused by the change in the marginal propensity to consume by agents, keeping their individual incomes on maximal level. Further, with the fall in the aggregate income, both variables start to fall much more dramatically. The bottom of the aggregate income is lower than the bottom in the aggregate demand, which is in line with the assumption that consumers prefer to maintain their consumption spending even for the price of decreasing their assets.

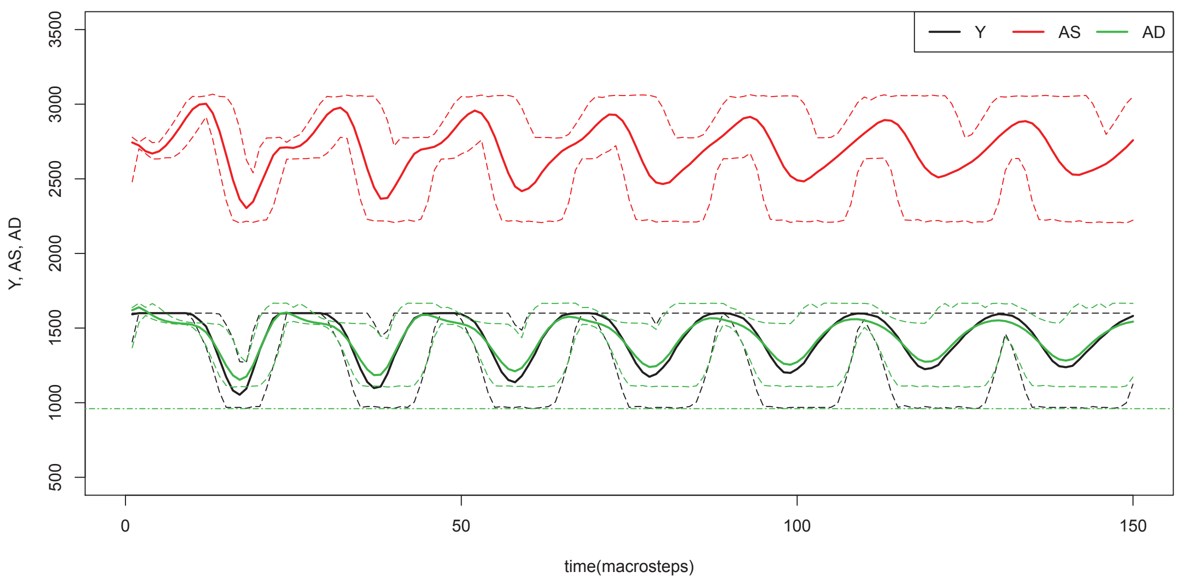

Figure 5.8: Aggregate income (Y), aggregate supply (AS) and aggregate demand (AD) - statistical evaluation.

The statistical evaluation, presented in Figure 5.8 is in line with the conclusion of the simulation of one run. The mean values are behaving cyclically, the cycle of the mean value of the aggregate income is harmonized with the cycle in the aggregated demand. The peak in the aggregate demand seems to be leading the peak in the aggregate income. The interesting result of this simulation is that, however the phases of an expansion in the business cycle in the aggregate income seem to be longer than the phases of a contraction, in case of the aggregate demand, according to the simulation the results are opposite.

We can observe that the phase of growth in the aggregate demand is, in the case of simulation for one run, as well as estimated by mean value, much shorter than the fall in the aggregate demand. The reason for this follows from the analyses of the behavior of the aggregate demand and the aggregate income presented for the baseline as well as extended versions of the model. The aggregate demand is, in the phase of expansion, growing together with the aggregate income. Once the firm meets its upper production limit (set by the maximal labor force of M agents), the production, as well as the aggregate income (equal to the production), is for some period ramining at this level. However, with the spread of optimism the aggregate demand is still rising. During the growth of optimism among the agents, the agents start to change their marginal propensity to consume in favor of their savings, until it causes the fall in the aggregate demand. Because the level of production was due to its upper burden for a longer period under its target outcome, the fall in the production and thus, in the aggregate income follows the aggregate demand with some lag.

The downturn in the aggregate demand, as well as in the aggregate income, is observed in the same time (as it was already explained, it is caused by the fact that an increase in the production is immediately projected into the increase of the aggregate income and through the individual incomes into the agent's demand for consumption spending).

As we can observe, for example, in Figure 5.8, the fall in the aggregate demand is occurring much sooner than in the aggregate income hereat, the increase in their downturn is synchronized. Because we consider the beginning of the contraction the moment when the variable starts to fall, the phase of contraction is in the aggregate demand starting much sooner than in the aggregate income (which is for some time still remaining at its upper maximal level), causing that the phase of expansion is, in the aggregate demand, shorter than the phase of contraction and in the aggregate income, on the contrary, the phase of expansion longer than the phase of contraction. The reason is thus, that upper production limit causes that the fall in the aggregate income due to the fall in the aggregate demand is lagged, prolonging the period of fall in the aggregate demand and the period of "growth" (stagnation exactly) in the aggregate income.

As in the baseline model, we can make a conclusion that the development of the aggregate demand is strongly connected to the development of the aggregate income, it is although not confirming but at least it is in line with the hypothesis that the fluctuations in the aggregate demand can cause the fluctuations in the aggregate income.

The aggregate supply is, in both Figures 5.7 and 5.8, again always higher than the aggregate demand. The amplitude in the cycles of all observed variables is decreasing because of the randomness in business cycle timing. The mean value of the aggregate demand during the run is slightly bigger than the mean value of the aggregate income (results in Table 5.4). The lowest variability is in the aggregate demand, followed by the aggregate income and the biggest is by the aggregate supply (Table 5.4). This is, again, in line with the production target, which is following the fluctuations in the aggregate demand. The fluctuations in the aggregate supply are increased by the fluctuations in inventory.

Statistics	Y	AS	AD
Mean	1439.364	2696.587	1438.936
Standard deviation	221.692	239.791	169.86
Median	1600	2716.738	1525.497
Min	962.406	2203.836	1103.534
Max	1600	3067.002	1667.422
1st Quantile	1263.158	2579.699	1291.375
3rd Quantile	1600	2858.74	1562.107

Table 5.4: Aggregate income (Y), aggregate supply (AS) and aggregate demand (AD) - descriptive statistics.

To evaluate the main goal of the thesis, e.g. to find out if the waves of optimism/pessimism in the consumers' confidence could generate the cyclic movement in the aggregate income, we further investigate the relationship between the indicator of confidence and the aggregate income, too. Simulations from both variables together with the aggregated adjustment of the marginal propensity to consume within one run are compared in Figure 5.9 and Figure 5.10.

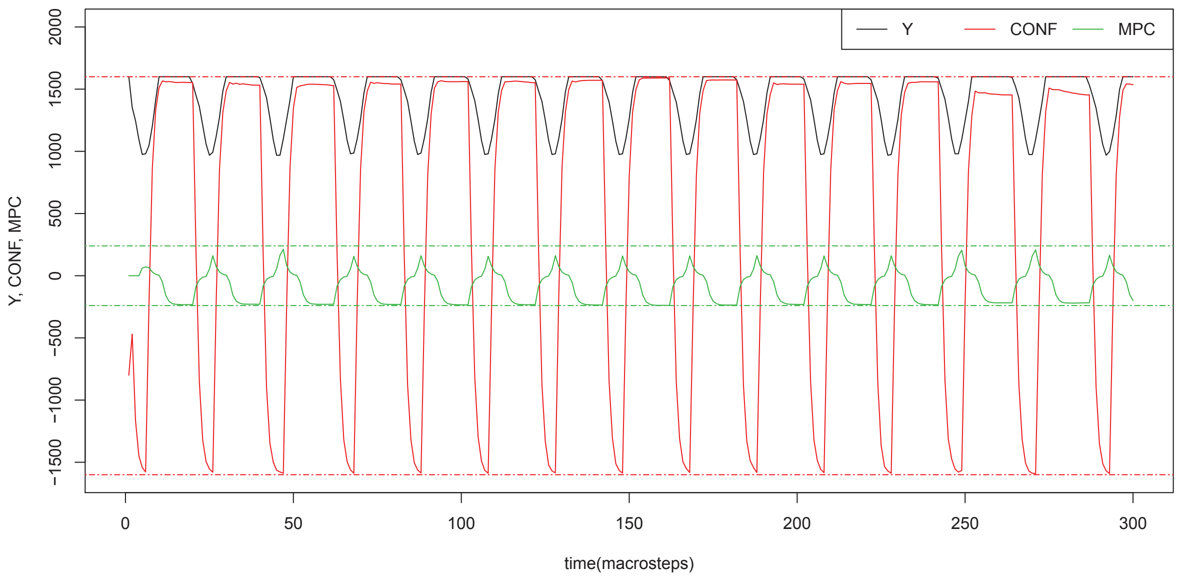

Figure 5.9: The consumer confidence indicator, aggregate income and marginal propensity to consume.

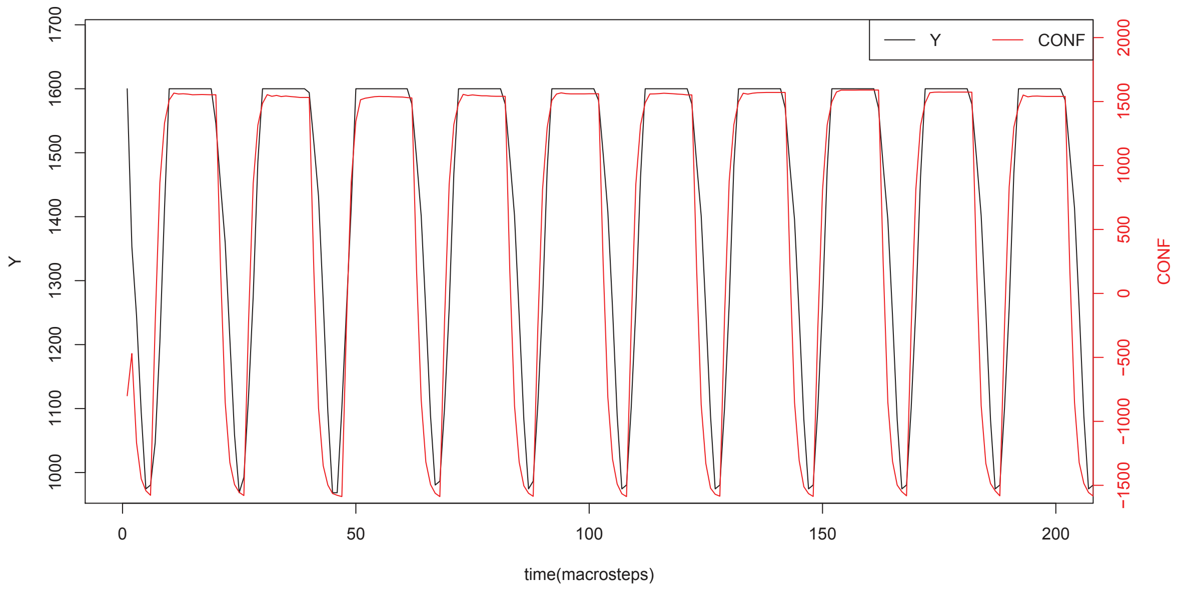

Figure 5.10: The consumer confidence indicator versus aggregate income.

We can see from both graphs the mutual comovement of the aggregate income with the aggregate indicator of the confidence in society ($CONF$). From Figure 5.9 it is observable that the peaks in the aggregate income and confidence are connected with the cases when the majority or all agents adjust their consumption spending in favor of savings. As we can see, the value of the indicator of marginal propensity to consume MPC on the aggregate level is very often, but not always, reaching its minimum (the case when all agents are optimists and already switched their marginal propensity to consume for preference of savings). Thus, it seems from the simulation result that it is enough when the critical mass changes their marginal propensity to consume and the fall in the aggregate demand and in the aggregate income occurs.

During the bottom, the influence of the critical mass is even stronger. In the case of the bottom of the aggregate income, the aggreagte indicator MPC is in 5.9 never reaching its maximum (equal to the case, when all agents are pessimists and switch their marginal propensity to consume in favor of the immediate consumption spending). Thus, it is enough when the critical mass of agents start to prefer immediate consumption on the cost of their dissavings and the turn in the aggregate income occurs.

This asymmetry could be, again, explained by the slow reaction of the aggregate income on the fall in the aggregate demand explained already before. As the aggregate demand starts to fall because of the critical mass changing their marginal propensity to consume in case of expansion, the production is at its upper limit and is keeping at this level for some time. Thus, even if the aggregate demand is already decreasing, the agents' income is not, supporting the spread of optimism among agents. The number of optimists and therefore the number of the agents continuing to switch their marginal propensity to consume in favor of savings is still rising for some period, until the agents' income is not falling. On the contrary, in case of the bottom, once the critical mass of agents decides to change their marginal propensity to consume in favor of immediate consumption spending, the production together with the aggregate income starts to grow. The increase in the agents' income directly supports the change in their confidence and the spread of pessimism is slowed down and switched into the spread of optimism anew.

The lag or the lead of the aggregate income in comparison to the confidence could be analyzed from Figure 5.10. It seems from the graph that the indicator of confidence is a leading variable of the aggregate income, however, the turning points of both variables are rather similar or in the case of downturns the aggregate income could turn up sooner. But, this behavior is not against the hypothesis that the fluctuations in the consumers' confidence could cause, through the aggregate demand, the fluctuations in the aggregate income. As was already explained above, the change in the consumer confidence could lead to the change in his/her marginal propensity to consume. Once the critical mass makes this change, it can cause the change in the aggregate income (through the aggregate demand). However, the change in the aggregate income means the change in the agents' income, influencing their confidence. Because there is still the impact of the neighbourhood on their confidence, the level of confidence reached by the critical mass could cause the turn in the development of the aggregate income, while still continuing to fall/increase, until it is turned too. The lead in the turning points in the development of one variable in comparison to the development of the behavior of another variable is in this sense not a necessary condition that the behavior of one variable is causing the behavior of the other. The simulation results thus do not confirm but are still in line with the hypothesis that the fluctuations in the consumers' confidence could cause the business cycle movement in the aggregate activity.

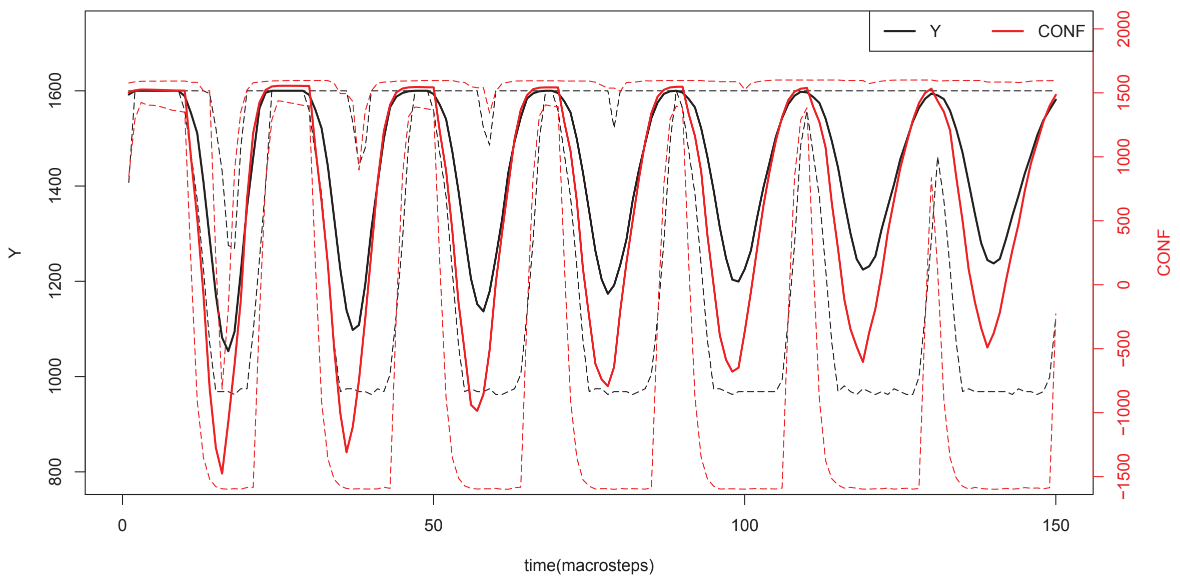

Figure 5.11: The consumer confidence indicator versus aggregate income - statistical evaluation.

The statistical evaluation is presented in Figure 5.11. The mean value of the aggregate income behaves cyclically, with the similar cyclical movement as the mean value of confidence, this time probably also during the turning points (there is no clearly visible lag or lead in all turning points from the graph). The synchronized development of both variables support the idea of the interconnection between the fluctuations in consumers' confidence and the aggregate income cycle movement.

As in previous cases, we can observe the decreasing trend in the amplitude of the cyclical behavior of the mean values, caused by the randomness of the business cycle. The increasing inconsistency in the timing of the peaks and bottoms of cycles could be observed by prolonging phases when the minimum and maximum values are in their extreme cases. The impact of the increase of macrosteps on the development of the mean values of variables was already explained before.

5.3.4 Production and investment

The production of the firm during one run is presented in Figure 5.12. We can see that the production at its peak is always equal to the production limit (black dot-and-dashed line in the graph) set by the full employment. During the phase of expansion the production nearly coincides with the aggregate demand. The turning point in the production is lagged with respect to the turning point in the aggregate demand. As was already explained before, the lag in the production is caused by the upper limit of the production. The aggregate demand has never reached its minimum (green dot-and-dashed line) which corresponds to the case when all agents consume its minimal consumption limit.

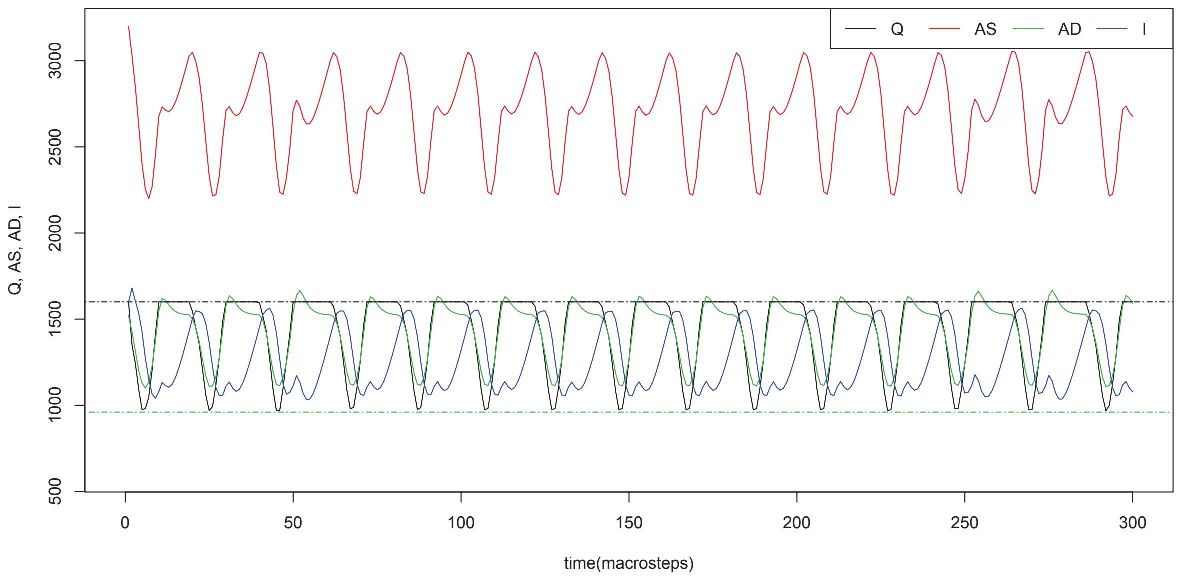

Figure 5.12: The aggregate supply (AS), production (Q) and inventory (I) during one run.

The inventory is growing with the aggregate demand. Once there is a turn in the aggregate demand, the inventory is firstly decreased. The reason for it is that the aggregate demand is high in comparison to the production stopped on its upper limit. Thus, the inventory is used to satisfy the surplus of the aggregate demand over the firm's production. With the fall in the aggregate demand, this surplus is decreasing until the moment, when the aggregate demand is lower than the firm's supply and the inventory is accumulating. With the decrease in the production, the firm is reducing its inventory. Thus, the development of the inventory is following the development of the production with some lag. Because the production is equal to the aggregate demand (from (4.20)), the results are in line with the first stylized fact (SF1) that the inventory lags the business cycle. The second stylized fact (SF2) is that the change in inventory is procyclical. According to the results presented in Figure 5.12 the inventory behaves procyclicaly (however, with some lag to the production, e.g. also to the aggregate income), the changes in inventory are positive during the phases of contraction and negative during the phases of contraction (with the lag). This is in line with the second stylized fact (SF2).

The aggregate supply is always higher than the aggregate demand, most of the time increasing. In the first phase, the aggregate supply grows with the growing production, later with the growing inventory. This result is in line with the firm's strategy to keep the inventory buffer stock for the unexpected fluctuations in the aggregate demand. Further, in the phase of contraction in the aggregate demand, the inventory is decreased rapidly.

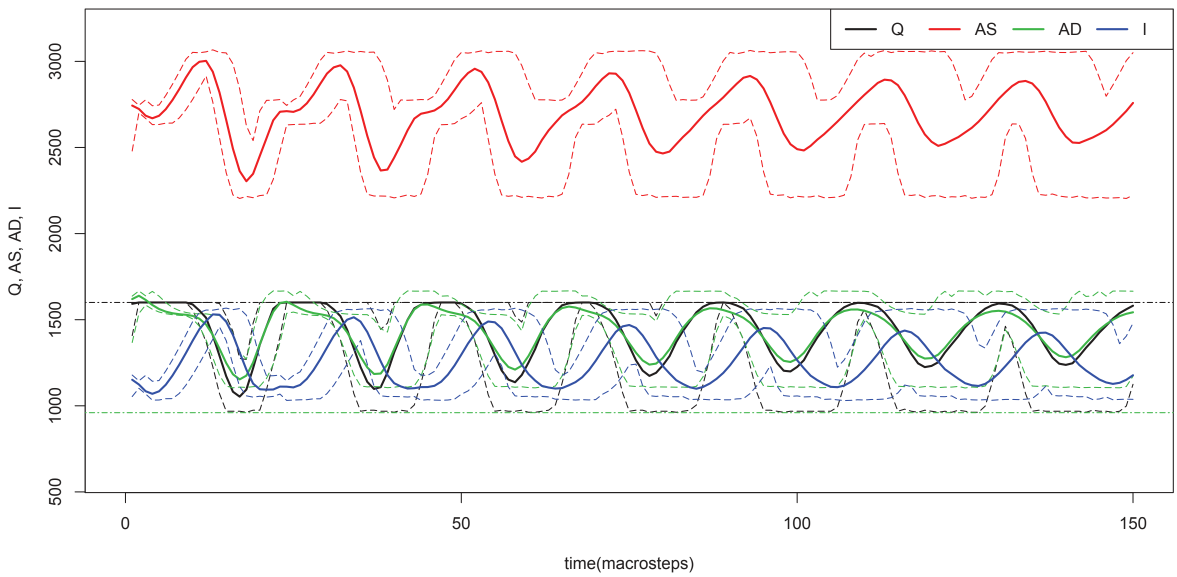

Figure 5.13: The aggregate supply (AS), production (Q) and inventory (I) - statistical evaluation.

The statistical evaluation of these variables could be seen in Figure 5.13 and in Table 5.5. The mean value of the aggregate supply is much higher than the mean value of the aggregate demand. From the Figure 5.13 we can see that the mean value of the aggregate demand could be a leading variable for determination the turn down in the production. The inventory is a lagged variable of both production and the aggregate demand, behaving procyclicaly (in line with the first and the second stylized fact (SF1) and (SF2)). We can see, again, the decreasing tendency in the amplitude of cyclic behavior of all variables, caused by the randomness in the business cycle timing. According to the results from Table 5.5 the lowest variance is in the aggregate demand, followed by inventory and production, the highest variance is in the aggregate supply.

Statistics	AS	AD	Q	I
Mean	2696.587	1438.936	1439.364	1257.223
Standard deviation	239.791	169.86	221.692	177.171
Median	2716.738	1525.497	1600	1188.191
Min	2203.836	1103.534	962.406	1030.377
Max	3067.002	1667.422	1600	1567.082
1st Quantile	2579.699	1291.375	1263.158	1104.555
3rd Quantile	2858.74	1562.107	1600	1414.529

Table 5.5: The aggregate supply (AS), production (Q) and inventory (I) - descriptive statistics.

5.3.5 Consumption

The aggregate income and its distribution into the aggregate savings and aggregate consumption can be found in Figure 5.14. During the phase of an expansion, the aggregate consumption is growing with the aggregate income. After reaching its peak, the aggregate consumption is slowly decreasing, the aggregate income remains, for some period, on its maximal level. This situation reflects the agents' preference for saving to the immediate consumption. During this period, the savings and assets of agents are accumulated. With the decrease in the aggregate income, the agents' wealth as well as savings are decreasing too, followed by a lagged decrease in consumers' assets.

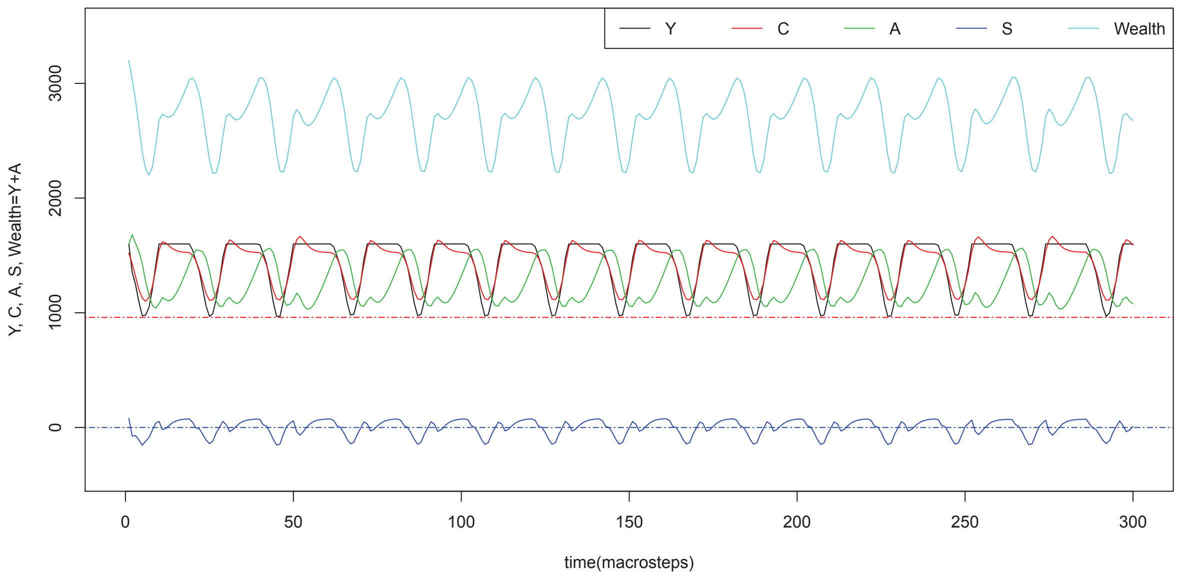

Figure 5.14: The distribution of consumer's income during one run.

The aggregate consumption has never reached its minimal value determined by the minimal level of consumption by all agents (red dot-and-dashed line in the graph). During the bottom in the aggregate income, the consumption is higher than the aggregate income, financed from the agents' assets. This is in line with the individual consumption demand definition, when in case of low income, agents prefer to maintain the consumption level even for the price of the reduction in their assets. This is the case when the savings are negative. For better orientation between negative and positive savings, we added the blue dot-and-dashed line in Figure 5.14 to represent the zero line. The results are consistent with the third stylized fact (SF3) that the development of consumption is procyclical and with the forth stylized fact (SF4) that the consumption is the biggest part of the aggregate income and its development is in comparison to the development of the aggregate income more smoothed.

The similar interpretation could be concluded from the statistical results in Figure 5.15. The development of the mean value of the consumption is, in comparison to the development of the mean value of the aggregate income, smoothed, the lower variance is compensated by the opposite cyclic behavior of the mean value of savings.

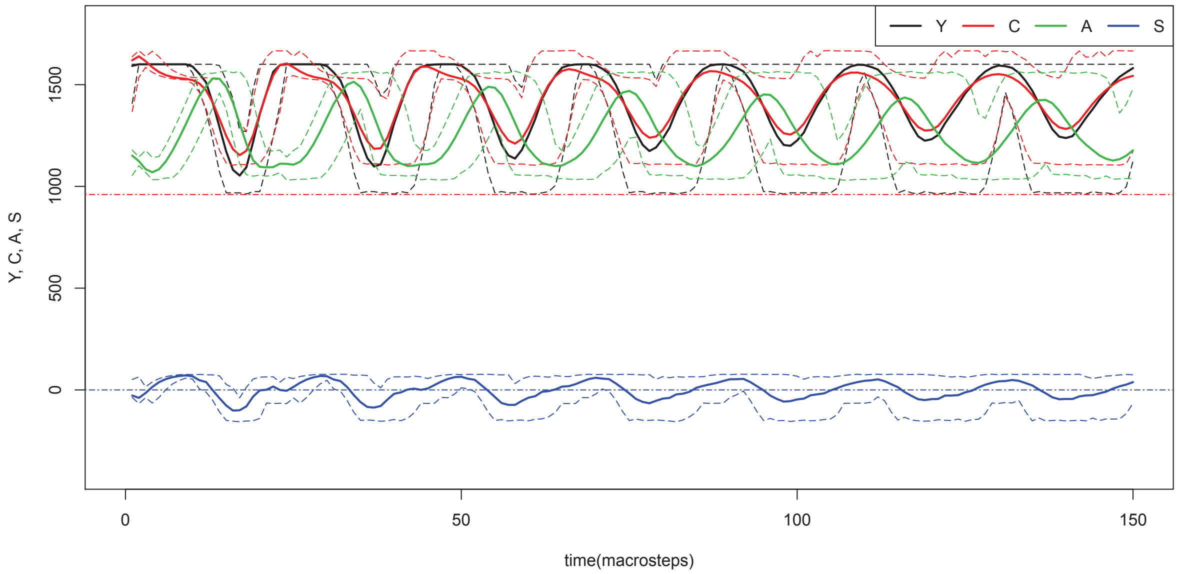

Figure 5.15: The distribution of consumer's income - statistical evaluation.

Statistics	Y	C	A	S
Mean	1439.364	1438.936	1257.223	0.429
Standard deviation	221.692	169.86	177.171	65.508
Median	1600	1525.497	1188.191	12.154
Min	962.406	1103.534	1030.377	−156.455
Max	1600	1667.422	1567.082	77.194
1st Quantile	1263.158	1291.375	1104.555	−37.426
3rd Quantile	1600	1562.107	1414.529	58.988

Table 5.6: The distribution of consumer's income - descriptive statistics.

The lower variance of the consumption spending than in aggregate income is also visible in the statistical results from Table 5.6. This is again in accordance with the stylized fact about the aggregate consumption, which is supposed to be procyclical (SF3) and more smoothed than the aggregate income (SF4). The high volatility of the aggregate income caused by the volatility in savings (which corresponds to the investment) is in line with the fifth stylized fact (SF5).

5.3.6 Labor market

The situation on the labor market is presented in Figure 5.16 and 5.17.

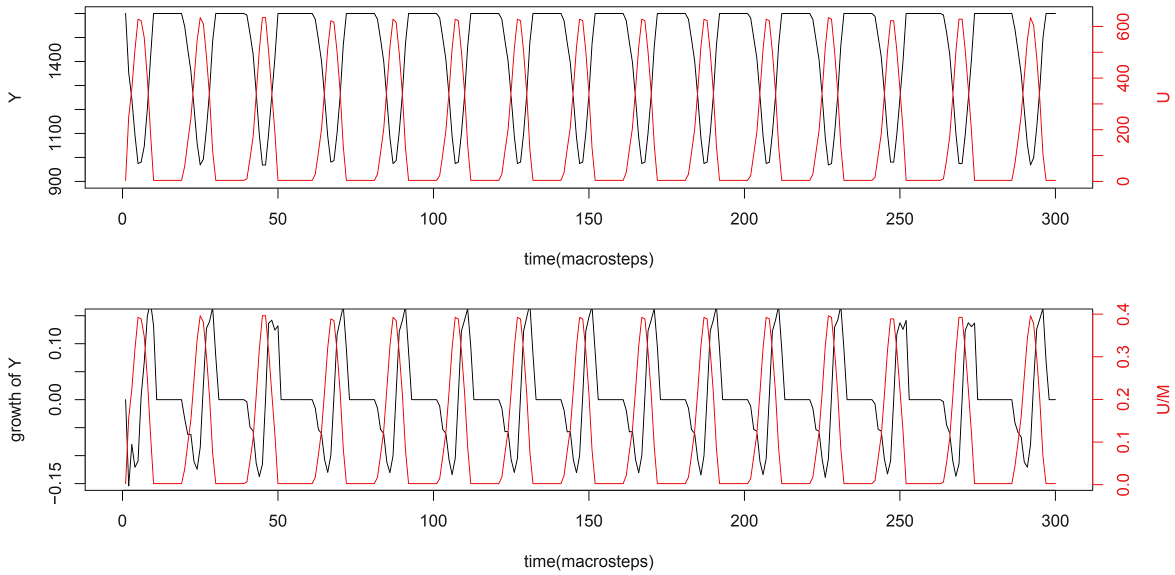

Figure 5.16: The aggregate income (Y) versus the rate of unemployment (U/M) during one run.

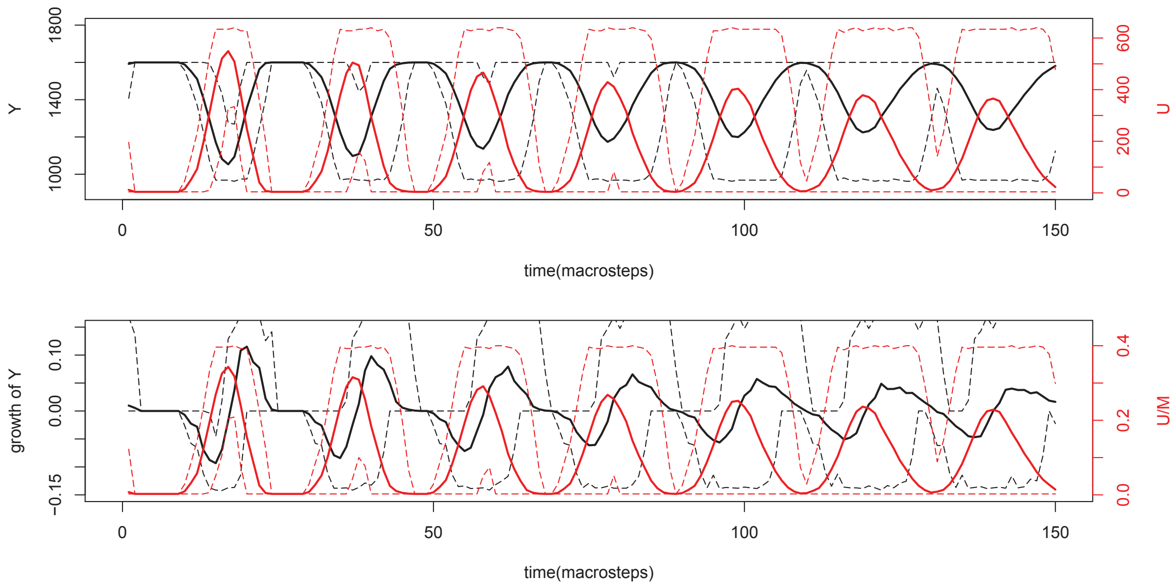

Figure 5.17: The aggregate income (Y) versus the rate of unemployment (U/M) - statistical evaluation.

We can observe an inverse relationship between the aggregate income and the number of unemployed agents in the first graph in Figure 5.16. As the aggregate income equals to the production in the model (from (4.20)) and the production is the linear function of the labor (equation (5.4)), the unemployment is decreasing when the aggregate income is increasing and vice versa. The relationship between the growth of the aggregate income and the rate of unemployment (counted as a percentage of U/M) confirmed that the positive growth in aggregate income is connected with decreasing unemployment rate and vice versa (this is in line with the Okun's law).

The same result is confirmed by the statistical evaluation presented in Figure 5.17. The mean value of the growth of income is estimated to be 0.003 (estimation results in Table 5.7), which corresponds to the model setting, where is no permanent trend in the aggregate income considered.

Statistics	growth of Y	The unemployment rate (U/M)
Mean	0.003	0.103
Standard deviation	0.074	0.138
Median	0	0.002
Min	−0.142	0.002
Max	0.173	0.4
1st Quantile	−0.019	0.002
3rd Quantile	0	0.212

Table 5.7: The aggregate income (Y) versus the rate of unemployment (U/M). - descriptive statistics.

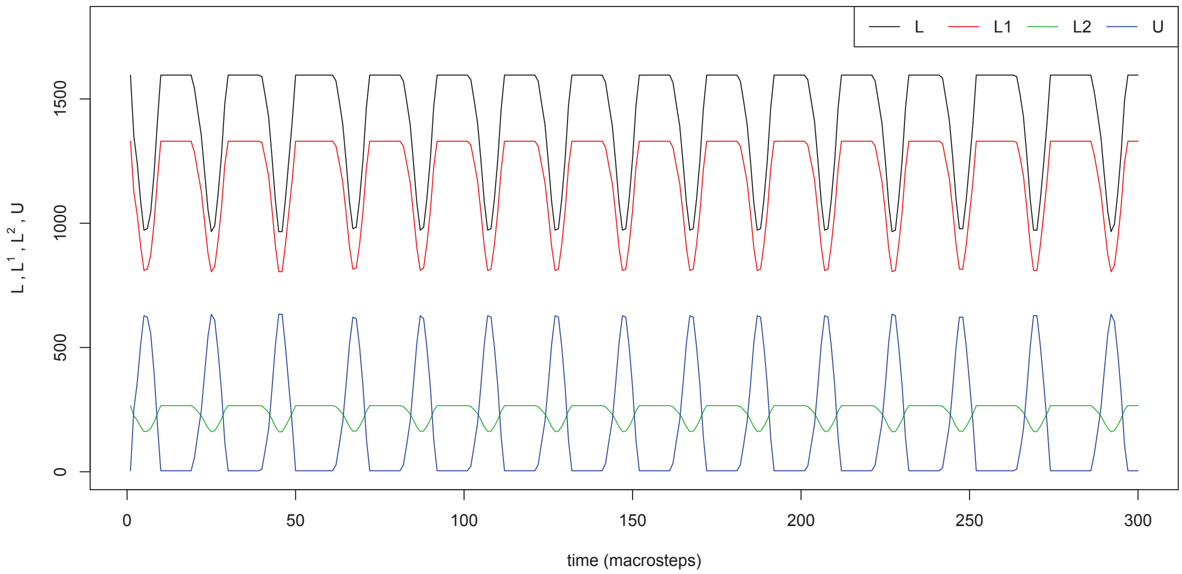

Figure 5.18: The labor (L), 1st-tier workers (L^1), 2nd-tier workers (L^2) and unemployed (U) during one run.

The distribution of the labor force from the simulation for one run is plotted in Figure 5.18.

The amount of agents working in production is evolving cyclically with the maximal value 1596 agents (the full employment) reached during peaks in economic activity.

Because we consider that the amount of hours worked by each employed agent is constant, the development of the labor expressed in worked hours is procyclical, which is the sixth stylized fact (SF6). The variability in working managers (L^2) is much lower than the variability in the amount of 1-st tier workers (L^1), which corresponds to the labor structure defined by the equation (5.1) and the ninth stylized fact (SF9). The employment is also presented with its distribution to 1st-tier and 2nd-tier workers. We can see that the reduction of the workforce is done mainly from the 1st-tier workers. The same conclusion can be made from the mean values of these variables presented in Figure 5.19. The lower variance of the 2nd-tier workers is confirmed by the results in Table 5.8.

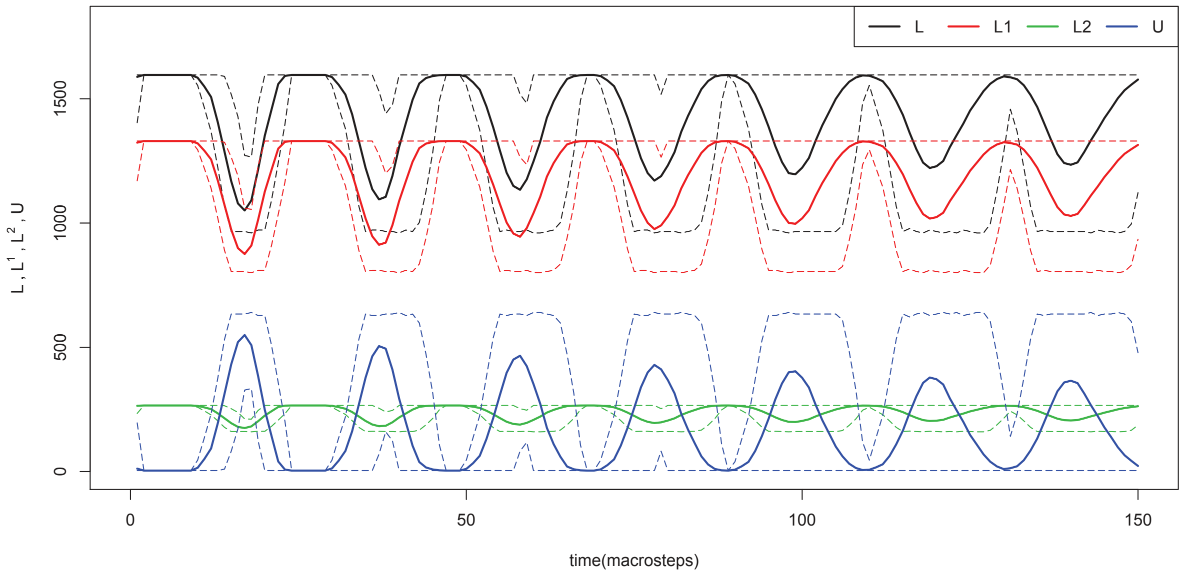

Figure 5.19: The labor (L), 1st-tier workers (L^1), 2nd-tier workers (L^2) and unemployed (U) - statistical evaluation.

Statistics	L	L^1	L^2	U
Mean	1435.766	1196.472	239.294	164.234
Standard deviation	221.138	184.281	36.856	221.138
Median	1596	1330	266	4
Min	960	800	160	4
Max	1596	1330	266	640
1st Quantile	1260	1050	210	4
3rd Quantile	1596	1330	266	340

Table 5.8: The labor (L), 1st-tier workers (L^1), 2nd-tier workers (L^2) and unemployed (U) - descriptive statistics.

The development of the real wages of all workers during one run is depicted in Figure 5.20, its statistical evaluation in Figure 5.21. Although the price level in the model is constant, real incomes of agents are not. The variability in incomes is caused by supporting the unemployed agents through the balanced social fund is low as well. Hence, during the times of expansions in the economic activity, the unemployment rate is low and thus the need for financing the social fund. The wage of workers grows. Because the social contribution paid to the unemployed is defined as a multiple of the wage from the 1st-tier worker (equation (5.8)), this social contribution grows too.

By analogy, during contractions in the economic activity, the number of unemployed agents grows, so the income earned by working agents has to be redistributed in a way to support more non-working agents. Thus, the wage of all tier workers and social contribution fall. This behavior corresponds to the seventh and eighth stylized facts that the labor income (SF7) as well as the real wages (SF8) are developing procyclically. Further, it is also in accordance with the results presented by Rayack (1987), who investigated the behavior of the real wages with respect to occupation category within the business cycle. Rayack (1987) confirmed that the real wages of laborers as well as managers evolves procyclically. The high variability in wages of 2nd-tier workers is in line with the definition of their wage structure in (5.7).

The mean values together with achieved minimum and maximum values are presented in Figure 5.21. The results are in line with the conclusion made from one run. We can see in the graph the converging tendency of all mean values to the mean values of these variables across the whole cycle (estimated in Table 5.9), caused by the randomness in business cycle timing. Standard deviations and mean values of all consumers' incomes in Table 5.9 correspond to the defined structure, the lower variance is in the income from social contribution, the highest in wages for 2nd-tier workers.

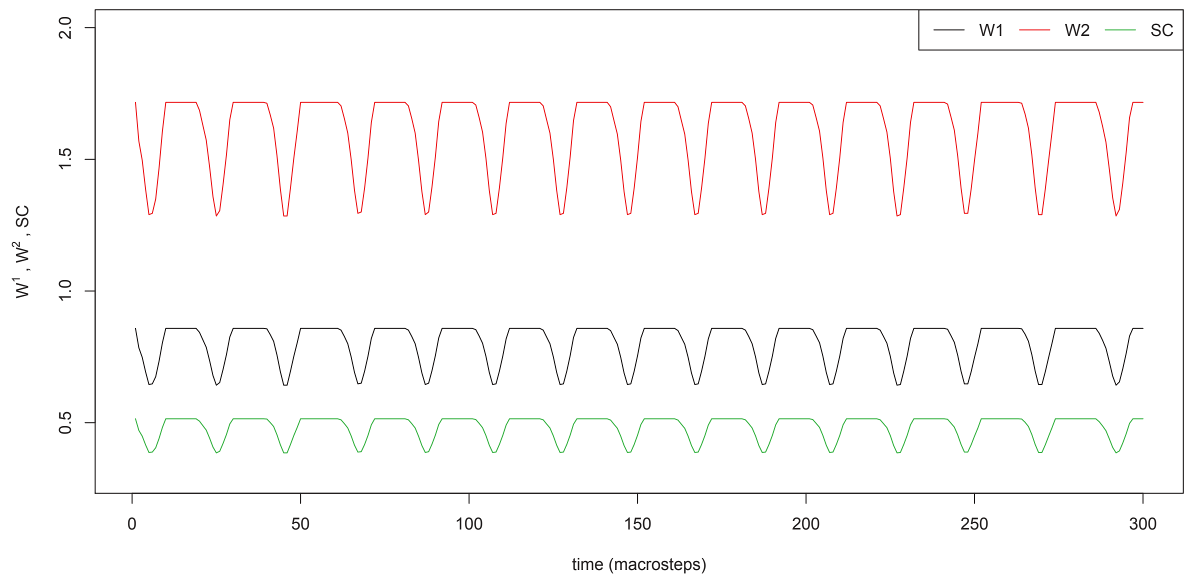

Figure 5.20: The wage of 1st-tier workers (W^1), 2nd-tier workers (W^2) and social contribution (SC) during one run.

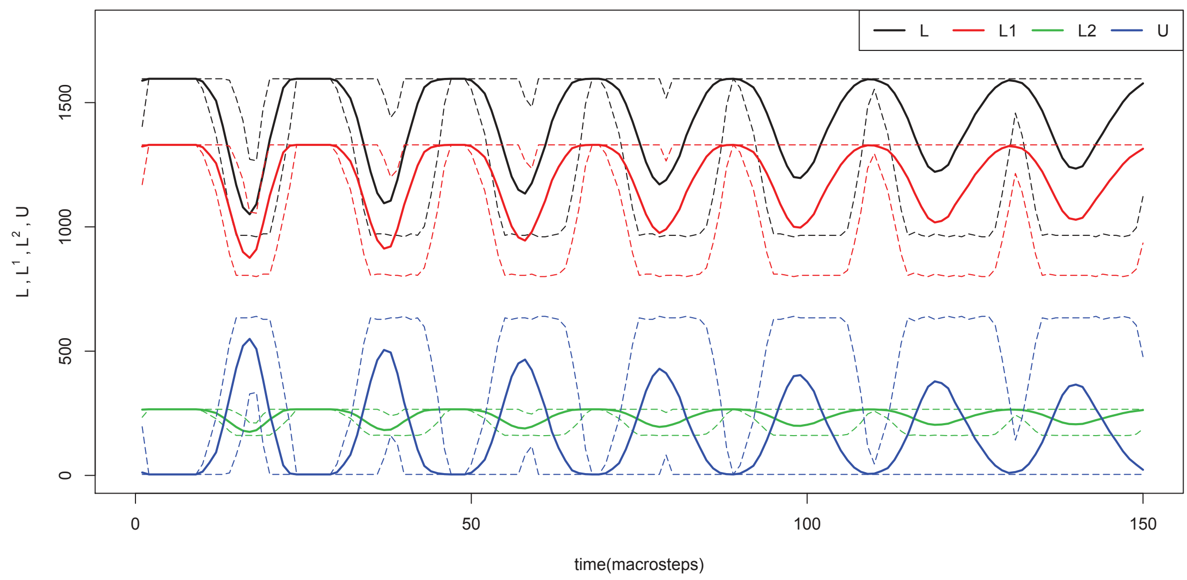

Figure 5.21: The wage of 1st-tier workers (W^1), 2nd-tier workers (W^2) and social contribution (SC) - statistical evaluation.

Statistics	W^1	W^2	SC
Mean	0.806	1.613	0.484
Standard deviation	0.074	0.147	0.044
Median	0.858	1.716	0.515
Min	0.64	1.28	0.384
Max	0.858	1.716	0.515
1st Quantile	0.755	1.509	0.453
3rd Quantile	0.858	1.716	0.515

Table 5.9: The wage of 1st-tier workers (W^1), 2nd-tier workers (W^2) and social contribution (SC) - descriptive statistics.

The simulaiton results from the extended version also support the partial and main hypotheses of this work, e.g. that the fluctuations in the consumer confidence could cause, through the fluctuations in the aggregated demand, the business cycle movement of the aggregate activity. The simulation results were in line with all stylized facts (SF1)-(SF9).

5.3.7 Business cycle

To analyze the business cycle movement, the count of cycle in the aggregate income during one run, the average period of the cycle, duration of its phases and the amplitudes during the phases were observed. These variables were measured and statistically analyzed in the same way as in the baseline model. The results could be found in Table 5.10.

We can see that the count of the cycles was estimated to 6 and according to the zero standard deviation it is a stable variable. The mean value of the period of the cycle was estimated to 20.648. As in the baseline case, the mean value of the duration of the phase of an expansion is much bigger than the mean value of the duration of the phase of a contraction. This is in line with stylized facts about business cycle presented by Gabisch and Lorenz (1989). The amplitudes during both phases are very similar, corresponding to the model definition.

Statistics	$Count$	$Period$	$Duration^E$	$Duration^C$	$Amplitude^E$	$Amplitude^C$
Mean	6	20.648	14.402	6.247	626.105	625.935
St.deviation	0	0.748	0.706	0.431	4.017	3.907
Median	6	20	14	6	625.564	625.564
Min	6	20	14	6	619.549	619.549
Max	6	22	16	7	637.594	637.594
1st Quantile	6	20	14	6	625.564	625.564
3rd Quantile	6	21	15	6	625.564	625.564

Table 5.10: The business cycle indicators - descriptive statistics.

5.3.8 Sensitivity analysis

The analysis of sensitivity for the extended version of the model was conducted in the same way as in the baseline case. Nevertheless we have now more parameters in the model, we have decided to control the sensitivity according to the same model parameters to be able to compare the results from both models. The parameter setting for different simulation tests is presented in Table 5.11.

	Parameter value during the sensitivity test			
	α^y	α^{mpc}	γ	T
Sensitivity on α^y	$0 \dots 1$	-0.15	0.55	1600
Sensitivity on α^{mpc}	0.5	$-0.4 \dots 0$	0.55	1600
Sensitivity on γ	0.5	-0.15	$0 \dots 1$	1600
Sensitivity on T	0.5	-0.15	0.55	$100 \dots 2500$

Table 5.11: Parameter setting for simulations.

The count of business cycles

We can see from the first graph in Figure 5.22 that the cyclic movement in the aggregate activity is achieved only for the values of α^y between 0.3 and 0.6 (for the exact values 0.3 and 0.6 the cycle is not observed). Thus, no or low weight setting for the influence of confidence in the neighborhood as well as no or low setting for the influence of the individual income on agent's confidence do not lead to cyclic movement in the aggregate income. We can see that by setting α^y between 0.3 and 0.6, e.g. giving to the influence of the confidence in the agent's neighborhood the weight between 0.4 and 0.7, the business cycle movement appears. Vice versa, giving only low or zero weight to the influence of the confidence in the agent's neighborhood on his/her confidence forming will lead to the stable aggregate income level without cyclic movement. The interval of this choice of α^y is in line with the results obtained also from the baseline model sensitivity analysis. However, for the baseline model, the cyclic behavior was achived also for the values 0.3 and 0.6. The simulation results support the hypothesis that the optimistic/pessimistic waves in consumer confidence could generate the cyclic behavior of the aggregate income (if there will be no or weak spread of the confidence among the agents through their neighbourhood, there will be no cyclic movement, once there is this spread and the role of agent's income is also considered, the cyclic movement appears).

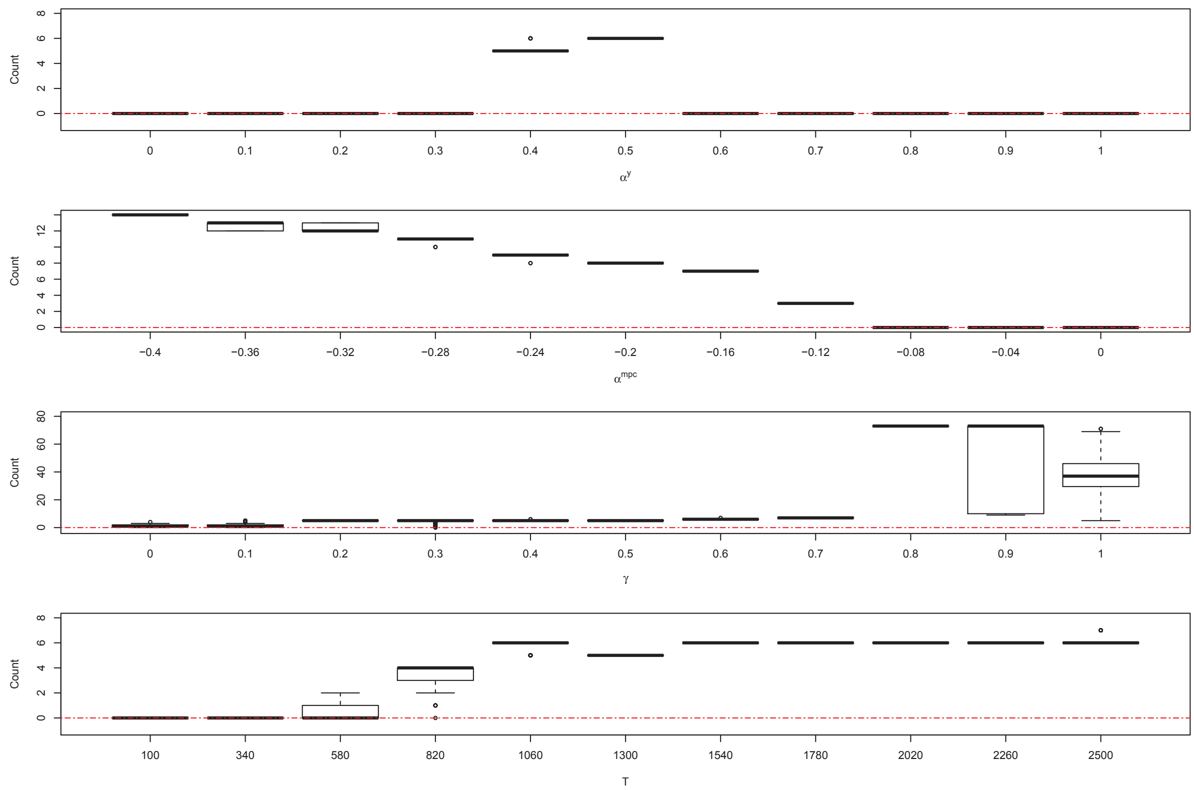

Figure 5.22: The count of cycles in one simulation run (*Count*) - boxplots.

According to the second graph in Figure 5.22 the cycle movement could occur for α^{mpc} lower than -0.12, which is the same results that we have obtained from the baseline model. Thus, the count of the business cycles positively depends on the extent of the change in the marginal propensity to consume (represented by the parameter α^{mpc}).

The sensitivity of the count of the cycle on the parameter γ is high. We can see the growing tendency of the count of the cycles when parameter γ grows from 0 till 0.9, very high values are achieved for the values 0.8 and 0.9. As this parameter reflects the agent's habit in the consumption spending, it seems that the cycling behavior in the aggregate income is slower when the agents are more flexible in adjusting their consumption spending to the target consumption demand. Although, this result may sound puzzling, it was already explained in the baseline model with the simulation results from the amplitude of the business cycle. The high frequency of the business cycle movement was connected with the low amplitude of this cycle. We will focus on the explanation of this behavior within the simulation results of the business cycle amplitude later.

Increasing the number of microsteps (T) has an impact on the spread of the confidence in the society. For values of T lower than 580 there is no cyclic movement. The reason could be similar to the case when there is low weight for the impact from the agent's neighborhood on his/her confidence forming. With the low value of microsteps only few agents reconsider their confidence. Thus, the confidence in the society is not changing so flexibly and the steady state value of the aggregate income is achieved. For T higher than 580 the cyclic behavior appears. For T higher than 1060 the count of the cycles in the aggregate income is more or less stable around the value 6. If we compare the results with the results obtained form the baseline model, we can see that in case of baseline model the cyclic movement was always observed. Thus, it seems that with the heterogeneous labor market and the impact of the unemployment, the higher number of the microsteps for the spread of the confidence among agents is needed.

The average period of business cycles

The average period of the business cycle (boxplots of this variable in Figure 5.23) is corresponding to the estimated count of the cycles presented above.

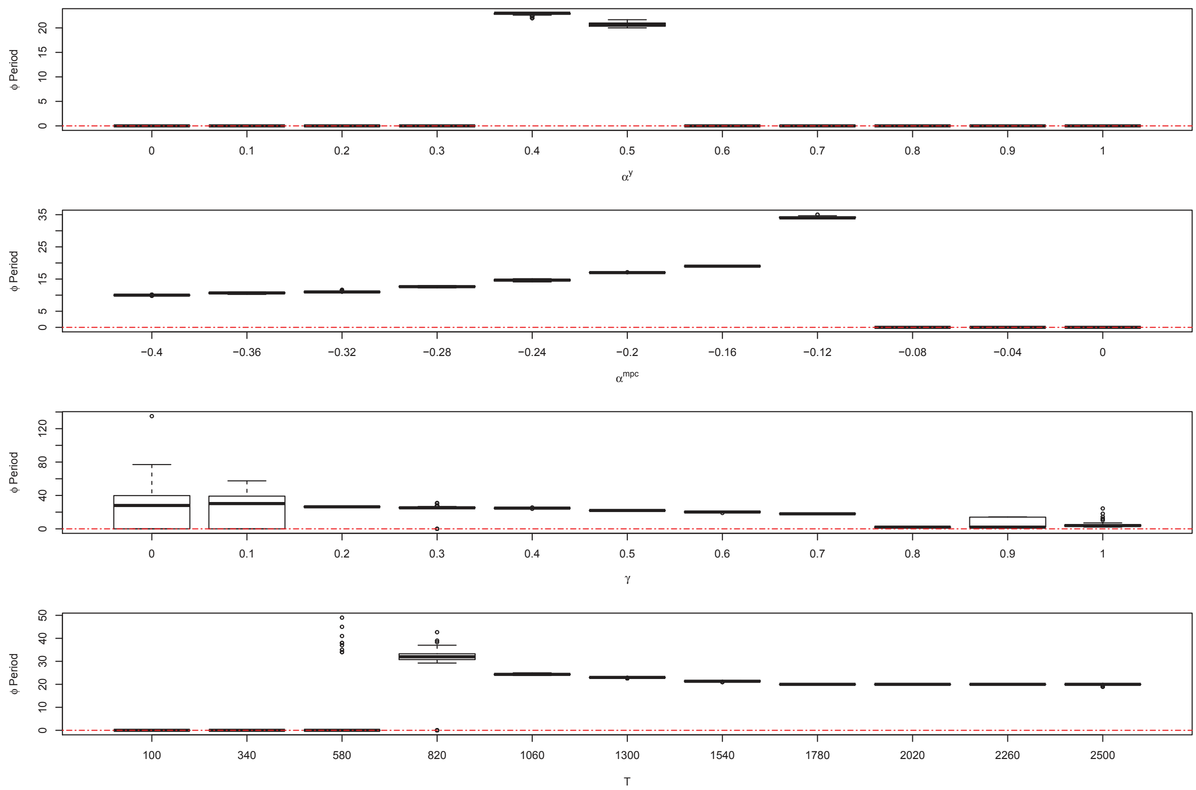

Figure 5.23: Average period of the business cycle.

In case of α^y lower than 0.4 or higher than 0.6 there was no cyclic movement, thus the period of the cycle is estimated to be zero. Otherwise, it is estimated around 20 cycles. As the count of the cycles is a decreasing when the change in the marginal propensity to consume (represented by α^{mpc}) is more flexible[41], the average period of the cycle is increasing with α^{mpc}. For α^{mpc} higher then -0.12 there is no cycle movement, thus the average period of the cycle is equal to zero. The average period of the business cycle for α^{mpc} equal to -0.12 is around 32 macrosteps, which is slightly higher than it was observed within the baseline model (20 macrosteps). The other simulation results are very similar to the results from the baseline model.

The average period of the business cycle negatively depends on the size of habit formation in the agent's consumption demand (expressed by the parameter γ). For γ lower than 0.8 the average period of the cycle is between 30 and 40 macrosteps, which is slightly more than it was observed for the baseline model (the average period was, for such parameter setting, between 15 to 25 macrosteps). The high count of the cycles for the values of γ 0.8 and 0.9 corresponds to the very short average period of the cycle. This time, the cyclic movement was observed during some simulations even for the extreme cases of this parameter, e.g. for the case of no habit formation or the case, when the agent's consumption demand is equal to his/her last consumption spending.

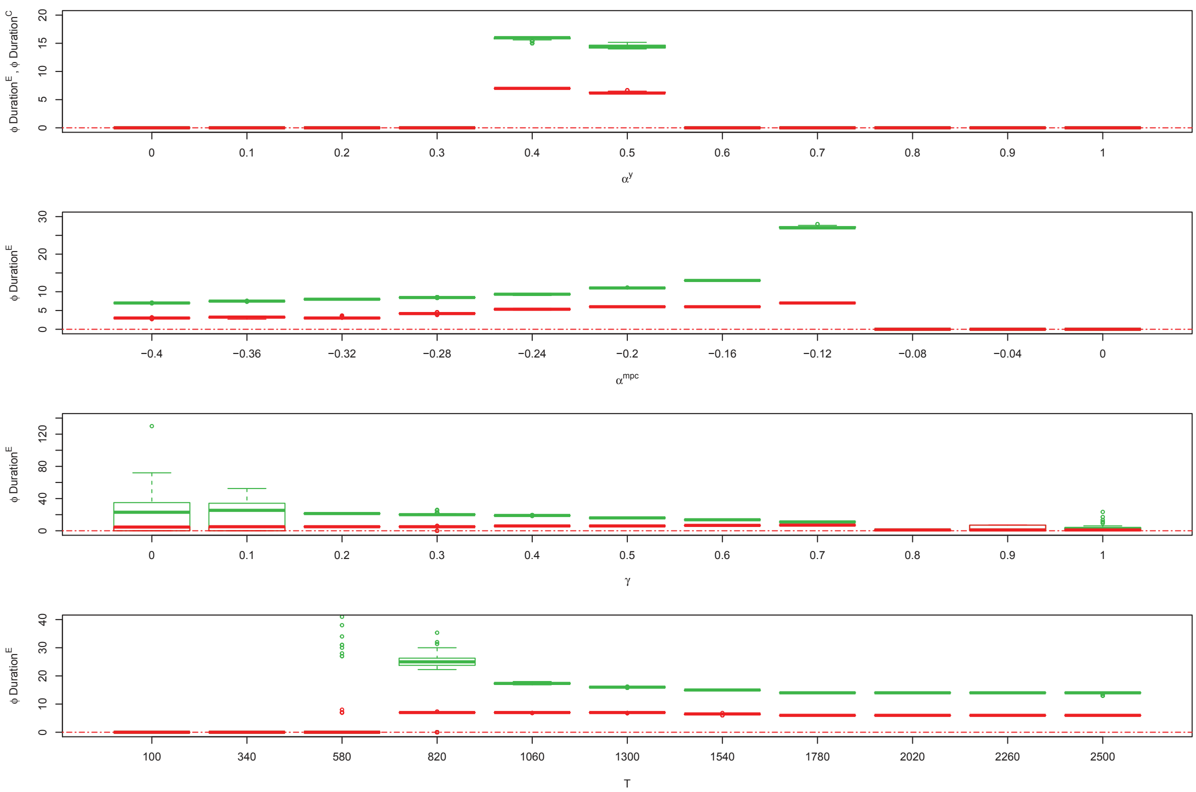

Figure 5.24: The average duration of the expansion and contraction phase in the business cycle.

Except for the very low values of T (number of microsteps), the period of the cycle has quite stable value between 20 and 30 macrosteps, with the very slow decreasing trend while T is increasing. The zero values of the average period of the business cycle for the number

[41]The negative value of α^{mpc} means the decrease of agent's marginal propensity to consume, e.g. the bigger is the absolute value of α^{mpc}, the higher is the flexibility in the adjustment of the marginal propensity to consume.

of microsteps lower than 580 are in line with previous simulation results, where there was, for these parameter values, no cycle movement observed.

According to the results presented in Figure 5.24, the average duration of expansion is, in majority of cases, higher than the duration of contraction if there is some cycle movement. The difference between these durations is sensitive to the size of habit formation (the parameter γ). The difference is increasing when the agents adjust their consumption spending more flexibly according to their target consumption spending (e.g. γ is decreasing). Further, it is decreasing with the higher amount of microsteps, e.g. when the simulation of consumer confidence among two subsequent macrosteps is longer and more agents are reconsidering their state of confidence. These results are in line with the results obtained form the simulations for the baseline model.

The average income during business cycles

The boxplots of the average aggregate income during one run are presented in Figure 5.25. In case of no business cycle movement the average income seems to be stabilized on its steady state value 1600, which correspond to the upper production limit of the firm. For α^y between 0.3 and 0.6, when the cyclic movement in the aggregate income appears, the average value of the aggregate income decreases to the value around 1400.

In case of the baseline model, the steady state value of the average income was for the values of α^y lower than 0.3 stabilized on the avergae income 960, corresponding to the minimum aggregate demand. In the extended version of this model, there is still no cycle movement for this parameter setting, however, the average income is stabilized on the level 1600, corresponding to the maximum level of production in the peak of aggregate activity. The parameter α^y expresses the weight of the changes in the agent's income on his/her confidence forming. While this weight is low, the state of agent's confidence is mainly formed according to the confidence in his/her neighbourhood. In the case of baseline model, the aggregate income was uniformly distributed, thus the changes in the agent's income were, in the extreme cases (the minimum aggregate demand, the maximum production), always small.

However, in the case of extended model, the labor market is heterogeneous. In case there is a fall in the aggregate income, some agents become employed/unemployed and thus their change in income is big. Because the target consumption is expressed according to the confidence but with respect to the immediate income, the big change in the income can lead to the big change in the agent's consumption demand. Thus, the aggregate demand seems to be more sensitive on the changes in the aggregate income even if the weight of the income in the confidence forming is low. In this case, however, the interpretation of this behavior is not straightforward and for clear explanation, the simulation results on the microlevel should be needed. Thus, we can only conclude that the introduction of the heterogeneous labor market into the model leads to different steady state value of the average aggregate income for low values of the parameter α^y.

The average aggregate income depends negatively on the size of adjustment in the marginal propensity to consume (represented by the the parameter α^{mpc}), which is the same result obtained aslo from the simulations for the baseline model. With the increase of this parameter the average income during the cycle grows from around 1250 to 1600.

In the baseline model, the average aggregate income during the run was decreasing while the size of habit formation in the consumption demand was increasing. In case of extended model, this is valid no more. The higher values of the aggregate income are obtained for the extreme values of the habit formation, e.g. for the values of γ close to zero (no habit formation) or close to one (high share of habit formation in the consumption demand). The lower average aggregate income (around 1430) seems to be achieved for γ around 0.5. The high value of habit formation (γ), however means the high level of rigidity in the consumption demand. We can see from the simulation results that the average aggregate income for such cases is close to 1530, e.g. close to the upper maximum of the production 1600), in the baseline model it was close to 1000, e.g. minimum aggregate demand. In both models, the high value of habit formation is connected with high count of business cycles with low amplitude (for the extended version presented later in Figure 5.26). We can only guess that this means that in both cases, there is a cyclic movement around the potential steady state, in case of baseline model this steady state will be the minimum aggregate demand while in the extended version, the maximum level of production. However, these results are the results from the interaction of agents on the lattice and the firm within complex model structure, thus, the straightforward explanation of this result is, in this case, not possible.

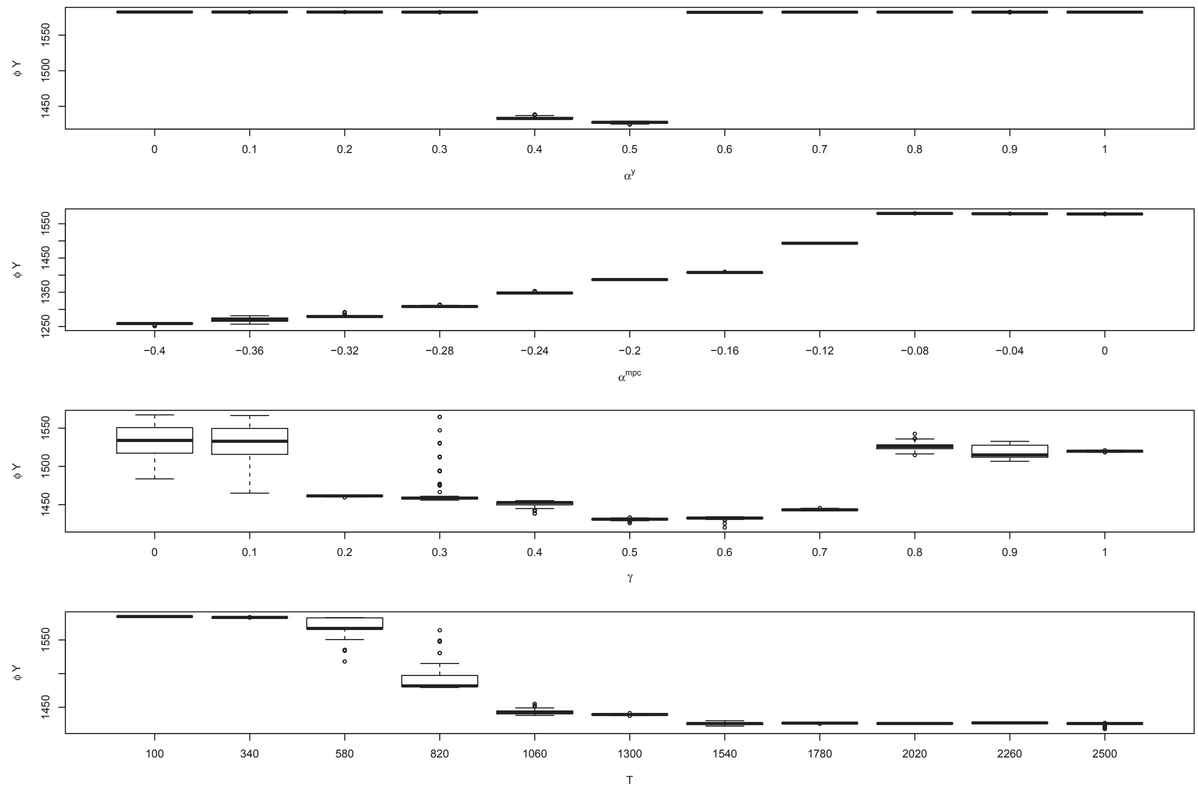

Figure 5.25: The average aggregate income during a run.

For low number of microsteps there was no cyclic movement observed and the average aggregate income is equal to 1600, which corresponds to the maximum level of production. With increasing number of microsteps, e.g. the number of agents reconsidering their state of confidence between two subsequent macrosteps is growing, the cyclic behavior appears. During this cyclic behavior, the average aggregate income is more or less stable around the value 1430.

The average amplitude of cyclical expansions and contractions

The boxplots of the average amplitude in the phase of expansion and the contraction of the business cycle are presented in Figure 5.26[42].

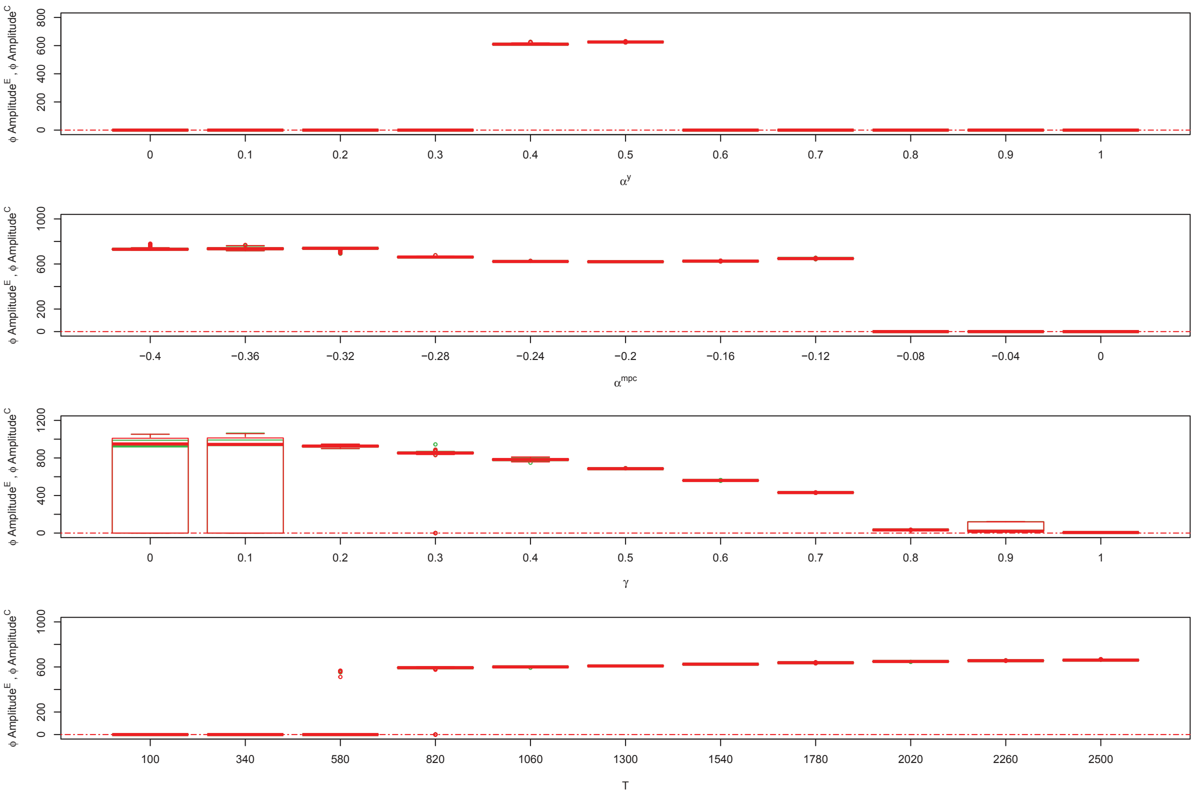

Figure 5.26: The average amplitude of the expansion and the contraction phase in the aggregate income cycle.

We can see that in case of no cyclic movement the amplitude is equal to zero. In other cases, the amplitudes for an expansion and a contraction are mainly equal. These results are very similar to the results obtained from the sensitivity analysis from the baseline model. We can observe that the increasing count of the cycles in the results from the sensitivity tests for the parameter γ (representing the habit formation in the consumption demand function) is connected with the decreasing amplitude during the phases of the business cycle. Thus, the higher frequency of the cyclic movement is connected with more smoothed behavior of the aggregate income. For the number of microsteps T higher than 580 (for lower number no cyclic behavior was

[42]For the exact definition of the amplitude, see Section 4.4.7.

observed) the amplitude of both phases seems to be stabilized around the value 600, which is slightly less than in the case of the baseline model, where the average amplitude was 800.

6 Conclusion

The main goal of the thesis was to find out, whether the spread of the waves of optimism/pessimism in consumer confidence in the agent based model could generate an endogenous cyclic movement of economic activity. In order to investigate this hypothesis, two agent based models were constructed.

Firstly, the simple baseline ACE model with the lattice of agents (consumers) and one production unit (firm) was built. The consumers were heterogeneous in their confidence and homogeneous in their income (the income was uniformly distributed among them). We have used the lattice of agents to simulate the spread of the consumer's confidence. During the simuation the randomly chosen agent was reconsidering his/her state of confidence (an optimist, a stable agent or a pessimist) according to his/her last income and the confidence in his/her neighbourhood. The consumer confidence then directly influences his/her individual consumption demand and according to the propagation mechanism, through the aggregated demand, further the production and the economic activity observed on the aggregate income.

The model was calibrated mainly in line with similar agent based models (Ciarli et al., 2010, Delli Gatti et al., 2011, Westerhoff, 2010) or studies for the estimations for initial model parameters (Havranek et al., 2015). The validation of the model was assessed according to the correspondence of its simulation results to the stylized facts about the macroeconomic variables presented by Kydland and Prescott (1990) and Gabisch and Lorenz (1989) or to Okun's law.

The main hypothesis of this thesis was investigated within its partial goals following the propagation mechanism of the influence of consumer confidence on the economic activity. Firstly, in line with the first partial goal, we were examining if the waves of optimism and pessimism in the consumer confidence could cause the cyclic movement in the aggregate demand for consumption spending. We have defined the aggregate indicator of confidence ($CONF$) to measure the level of consumer confidence in society. During the simulations we have observed the cyclical movement in this confidence indicator. This movement was distinguished between the waves of optimism and pessimism in consumers' confidence. Because the consumer confidence was one of the factors influencing the formation of the individual consumption demand, the aggregate demand was, in most cases, directly influenced too. This impact was decreased during the turning points in the aggregate demand, because the individual demand is limited from below by the minimal level of consumption spending and from above by the production possibility of the firm. We have observed, in the the simulation results, the comovement of these variables and the cyclic movement in the aggregate demand. The indicator of consumer confidence was a leading variable for the aggregate income. However, during the turning points the variables were mainly synchronized. The upper turning points seemed to happen in the aggregate demand first, followed with the turn in the consumers' confidence (we have explained this behavior by the lower and upper limitation of the aggregate demand). Albeit, according to the simulation results, the indicator of consumer confidence could be used for a predictive purposes of the upper turning points in the aggregate demand, because before its turning point there has always been an apparent slowdown in the growth of the consumer confidence.

Further, following the second partial goal, we were interested if the cyclic movement in the aggregate demand could be transferred into the cyclic movement in the aggregate income. According to the simulation results, the cyclic behavior of the aggregate income and the mutual cyclic comovement of both variables were observed. The development of both variables seemed to be synchronized. The differences were observed during the turning points in the development of these variables. According to the different turning points timing, an interesting observation was uncovered. The stylized fact about the business cycle movement, presented, for example, by Gabisch and Lorenz (1989), is that the phases of the expansion of the business cycle movement are usually longer than the phases of its contraction. This behavior was also observed during the simulations. However, the duration of expansion in the aggregate demand seemed to be shorter than the duration of its contraction. According to the simulation results, there is a long phase of growth in the aggregate income followed by the fast fall in it and the fast growth of the aggregate demand, followed by the slow fall in it.

We cannot test the causality of the spread of the waves of optimism/pessimism in the consumer confidence for the cyclic movement of economic activity (the main goal of the thesis) directly from the model simulations with our fixed parameter settings. However, all simulation results were not contradicting this influence. Thus, in addition, the sensitivity analysis for the parameter of the spread of the confidence $(1-\alpha^{y})$ was done. We have found out that, when the influence of the spread of the consumer confidence was very slow or zero, ceteris paribus, any cyclic movement in the aggregate activity was not observed, e.g. when the confidence in the agent's neigbourhood was an important factor for forming his/her confidence, the cyclic behavior in the aggregate income appeared. On the contrary, when the influence of the confidence around an agent was not important for his/her confidence, and so his/her confidence was mainly based on the change in his/her income, ceteris paribus, the cyclic behavior in the aggregate income was not observed.

These results were observed keeping all other parameters fixed. We have found out during the simulations that once the flexibility in the adjustment of the marginal propensity to consume is very low, the cyclic behavior in the aggregate income disappears. Our results concerning the main hypothesis of the thesis are based od the fixed parameter setting, where the adjustment in the marginal propensity to consume is rather flexible; this setting is in line with Keynes (1936), Deaton (1989) and Pollin (1988). According to these findings, we cannot reject the hypothesis of this thesis, that the waves of optimism/pessimism in the consumers' confidence could lead to the cyclic movement in the aggregate income.

Following the findings of Mueller (1966) and Malley and Moutos (1996), that the consumer confidence is strongly negatively influenced by the rate of unemployment, we have decided to build an extended version of this ACE model with heterogeneous labor market. By this model, we wanted to investigate if our conclusions remain stable also after considering this additional factor. This was set as a last partial goal of the thesis.

In the extended version of the model, we distinguished between two types of workers - 1st-tier workers and 2nd-tier workers (managers). During the simulations, all workers were hired or discharged by lottery, following the labor demand of the firm. The incomes of workers were adjusted respectively to this setting. The model was calibrated in line with a baseline model in order to allow us to compare the model results and according to the ACE model with heterogeneous labor market proposed by Ciarli et al. (2010). The validation of the model was tested on the business cycle stylized facts from Kydland and Prescott (1990) and Gabisch and Lorenz (1989), extended for the case of heterogeneous workers.

The simulation results from the extended model were also in line with first and second partial goals of the thesis. We could observe the cyclic behavior of the aggregate confidence indicator, leading the cyclic evolvement of the aggregate demand. Because of the upper limitation of the firm's production and lower limitation of the individual demands, this lead was not observed at the turning points of the aggregate demand. Further, we have observed the similar comovement of the aggregate demand and the aggregate income. Thus, we can conclude that the simulation results were in line with the last partial goal of the thesis, that the waves of optimism and pessimism in consumer confidence could be the source of endogenous cyclic movement in the economic activity within an ACE model with heterogenous labor market.

Similarly to the baseline case, we are not able to confirm the strict causality. However, also in the case of extended model, the sensitivity analysis on key model parameters were provided. The cyclic behavior in the economic activity was observed only in the case when the agent's confidence was influenced by the confidence in his/her nighborhood, ceteris paribus. Once this influence on his/her confidence forming was decreased, the cyclic behavior disappeared. In addition, we have found out that in the model with heterogeneous labor market, the cyclic behavior seemed to be even more sensitive on the changes in this influence. This time, the cyclical behavior of the aggregate income was not present even in the cases of the low number of microsteps (parameter T), which determines the length of the simulation for confidence spread. All the results were obtained, as well as in baseline model, for the flexible adjustment of the marginal propensity to consume.

The simulation results from both models together with the results from sensitivity analysis were in line with the main hypothesis, that the spread of the optimism/pessimism in the consumer confidence could cause the cyclic movement in the economic activity. As we have already emphasized, we cannot directly confirm that causality; however, all the results are very much in line with this. We have already obtained the similar results in the ACE model by Závacká (2016). The cyclic movement in the aggregate income was generated in the model of Westerhoff (2011) as well, in this model the movement was generated by the waves of optimism/pessimism in the confidence of firms.

Further, we would like to note, as we have already pointed out before, that the cyclic movement in the consumer confidence should not be understood as a primal and unique source of the business cycle movement but rather as a contributional factor. The business cycle movement should be rather understood as a result of various endogenous and exogenous sources. Although we should not consider the fluctuations in the consumer confidence as a primal source of the business cycle movement, admitting and investigating its participation on the business cycle movement could improve the policies for smoothing the fluctuations in the aggregate demand. Decreasing the impact of the consumer confidence on their individual consumption demand could lead to a decrease in the aggregate income fluctuations. Or on the other hand, supporting the optimistic confidence in times of contraction in the economic activity could be the way for its softening.

The baseline and the extended version of ACE model, simulating the spread of the confidence on the microeconomic level within the whole macroeconomy are, to our best knowledge, the first models of this kind in the Czech Republic. The ACE models dealing with the spread of confidence on the microeconomic level were already presented by Westerhoff and Hohnisch (2010) and Westerhoff (2010), but not in such microeconomic details. Because of this novelty, there is still a lot of space for future research in this field. We would propose to extend the model for the variable price level and the investment, to observe its impact on the cyclical movement in the aggregate activity. Further, the ACE model with heterogeneous labor market could be used for simulations on the labor market based on the changes on a microeconomic level. We can also use the model for observing the income inequality within the bussines cycle (was already presented in Závacká (2015c)), extend the model for simulating various fiscal or monetary policies and investigate their impact on the income distribution. The main advantage of those models is that they enable us to do the simulations and evaluations on the microeconomic level. Despite the complexity of this approach, its disadvantages (model calibration, computationally demanding, tough calibration on microeconomic data, etc.) we believe that, by considering the mutual interactions among the consumers or firms, we can obtain more realistic results.

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ZÁVACKÁ, Jana. Alternative roles of consumer confidence in forecasting consumption: Evidence from European countries. *Ekonomická revue*. 2016, vol. 19, no. 4, pp. 133–142.

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In Ostrava on 8.8.2017

Jana Závacká

The list of attachments

A.1 Model variables
A.2 Model equations - the baseline model
A.3 Model equations - the extended model
A.3 The code of the baseline model
CD The code of the baseline and the extended model, together with the codes for sensitivity analysis

A Appendix

A.1 Model variables

Variable	Description
Δmpc_t^i	Chnage in the marginal propensity to consume of the agent i in time t
A_t	Assets in time t
A_t^i	Assets of the agent i in time t
AD_t	Aggregate demand in time t
AS_t	Aggregate supply in time t
C_t	Consumption spending in time t
C_t^i	Consumption spending of the agent i in time t
$\bar{C}_t^i$	Target consumption spending of the agent i in time t
$CONF_t$	Aggregate indicator of confidence in time t
EQ_t	The realized sale in time t
$Expincome_t^i$	Expectations of the agent i about his/her future income in time t
I_t	Inventory in time t
ID_t^i	Demand for consumption spending of agent i in time t
$Influence_{t\tau}^i =$	Influence on the confidence of the agent i in time $t\tau$
L_t	Labour in time t
L_t^1	Amount of 1st-tier workers in time t
L_t^2	Amount of 2nd-tier workers in time t
$\bar{L}_t^1$	Demand for the 1st-tier workers in time t
$Mood_{t\tau}^i$	Confidence of the agent i in time $t\tau$
$Mood_t^i$	Confidence of the agent i in time t
MPC_t	Indicator of the marginal propensity to consume in time t
O_t	Number of optimists in society in time t
P_t	Number of pessimists in society in time t
S_t	Savings in time t
S_t^i	Savings of the agent i in time t
SC_t	Social contribution in time t
ST_t	Number of stable agents in society in time t
Q_t	Production in time t
$\bar{Q}_t$	Target production in time t
U_t	Amount of unemployed in time t
W_t^1	Wage of 1st-tier worker in time t
W_t^2	Wage of 2nd-tier worker in time t
Y_t	Aggregate income in time t
Y_t^i	Income of the agent i in time t

Table A.1: Model variables.

A.2 Model equations - the baseline model

$$Expincome_t^i = \begin{cases} 1 & Y_t^i > Y_{t-1}^i, \\ 0 & Y_t^i = Y_{t-1}^i, \\ -1 & Y_t^i < Y_{t-1}^i. \end{cases} \tag{A.1}$$

$$Influence_{t\tau}^i = \alpha^y \cdot Expincome_t^i + (1-\alpha^y) \cdot \frac{1}{4} \sum_{j \in Neighborhood} Mood_{t\tau}^j. \tag{A.2}$$

$$Mood_{t\tau}^i = \begin{cases} -1 & Influence_{t\tau}^i \leq -\frac{1}{3}, \\ 0 & -\frac{1}{3} < Influence_{t\tau}^i \leq \frac{1}{3}, \\ 1 & \frac{1}{3} < Influence_{t\tau}^i. \end{cases} \tag{A.3}$$

$$Mood_{t+1}^i = Mood_{t,TT}^i. \tag{A.4}$$

$$CONF_{t+1} = \sum_{i=1}^{M} Mood_{t+1}^i. \tag{A.5}$$

$$O_{t+1} = \sum_{\{i; Mood_{t+1}^i = 1\}} Mood_{t+1}^i. \tag{A.6}$$

$$P_{t+1} = \sum_{\{i; Mood_{t+1}^i = -1\}} Mood_{t+1}^i. \tag{A.7}$$

$$ST_{t+1} = \sum_{\{i; Mood_{t+1}^i = 0\}} Mood_{t+1}^i. \tag{A.8}$$

$$Y_{t+1}^i = \frac{1}{M} Y_{t+1} \tag{A.9}$$

$$\Delta mpc_{t+1}^i = \begin{cases} \alpha^{mpc} & Mood_{t-3}^i = Mood_{t-2}^i = Mood_{t-1}^i = Mood_t^i = Mood_{t+1}^i = 1, \\ 0 & Mood_{t+1}^i = 0, \\ -\alpha^{mpc} & Mood_{t-3}^i = Mood_{t-2}^i = Mood_{t-1}^i = Mood_t^i = Mood_{t+1}^i = -1. \end{cases} \tag{A.10}$$

$$MPC_{t+1} = \sum_{i=1}^{M} \Delta mpc_{t+1}^i. \tag{A.11}$$

$$\bar{C}_{t+1}^i = \begin{cases} (1 + x + \Delta mpc_{t+1}^i) Y_{t+1}^i & \text{optimist}, \\ Y_{t+1}^i & \text{stable agent}, \\ (1 - x + \Delta mpc_{t+1}^i) Y_{t+1}^i & \text{pessimist}. \end{cases} \tag{A.12}$$

$$ID^i_{t+1} = \max\left\{C^0; \gamma C^i_t + (1-\gamma)\bar{C}^i_{t+1}\right\}. \tag{A.13}$$

$$AD_{t+1} = \sum_{i=1}^{M} ID^i_{t+1}. \tag{A.14}$$

$$AS_{t+1} = Q_{t+1} + I_{t+1}. \tag{A.15}$$

$$\bar{Q}_{t+1} = \max\left\{0; \min\{a^L M; 2EQ_t - I_{t+1}\}\right\}. \tag{A.16}$$

$$Q_{t+1} = a^L L_{t+1}. \tag{A.17}$$

$$Y_{t+1} = Q_{t+1}. \tag{A.18}$$

$$EQ_{t+1} = \min\{AD_{t+1}, AS_{t+1}\}. \tag{A.19}$$

$$EQ_{t+1} = C_{t+1}. \tag{A.20}$$

$$C^i_{t+1} = C_{t+1}\frac{ID^i_{t+1}}{AD_{t+1}}. \tag{A.21}$$

$$S^i_{t+1} = Y^i_{t+1} - C^i_{t+1}, \tag{A.22}$$

$$S_{t+1} = \sum_{i=1}^{M} S^i_{t+1} = Y_{t+1} - C_{t+1}. \tag{A.23}$$

$$A^i_{t+1} = A^i_t + S^i_{t+1}, \tag{A.24}$$

$$A_{t+1} = \sum_{i=1}^{M} A^i_{t+1} = A_t + S_{t+1}. \tag{A.25}$$

$$I_{t+2} = AS_{t+1} - EQ_{t+1}. \tag{A.26}$$

A.3 Model equations - the extended model

$$Expincome_t^i = \begin{cases} 1 & Y_t^i > Y_{t-1}^i, \\ 0 & Y_t^i = Y_{t-1}^i, \\ -1 & Y_t^i < Y_{t-1}^i. \end{cases} \tag{A.27}$$

$$Influence_{t\tau}^i = \alpha^y \cdot Expincome_t^i + (1-\alpha^y) \cdot \frac{1}{4} \sum_{j \in Neighborhood} Mood_{t\tau}^j. \tag{A.28}$$

$$Mood_{t\tau}^i = \begin{cases} -1 & Influence_{t\tau}^i \leq -\frac{1}{3}, \\ 0 & -\frac{1}{3} < Influence_{t\tau}^i \leq \frac{1}{3}, \\ 1 & \frac{1}{3} < Influence_{t\tau}^i. \end{cases} \tag{A.29}$$

$$Mood_{t+1}^i = Mood_{t,TT}^i. \tag{A.30}$$

$$CONF_{t+1} = \sum_{i=1}^{M} Mood_{t+1}^i. \tag{A.31}$$

$$O_{t+1} = \sum_{\{i;Mood_{t+1}^i=1\}} Mood_{t+1}^i. \tag{A.32}$$

$$P_{t+1} = \sum_{\{i;Mood_{t+1}^i=-1\}} Mood_{t+1}^i. \tag{A.33}$$

$$ST_{t+1} = \sum_{\{i;Mood_{t+1}^i=0\}} Mood_{t+1}^i. \tag{A.34}$$

$$Y_{t+1}^i = \frac{1}{M} Y_{t+1} \tag{A.35}$$

$$\Delta mpc_{t+1}^i = \begin{cases} \alpha^{mpc} & Mood_{t-3}^i = Mood_{t-2}^i = Mood_{t-1}^i = Mood_t^i = Mood_{t+1}^i = 1, \\ 0 & Mood_{t+1}^i = 0, \\ -\alpha^{mpc} & Mood_{t-3}^i = Mood_{t-2}^i = Mood_{t-1}^i = Mood_t^i = Mood_{t+1}^i = -1. \end{cases} \tag{A.36}$$

$$MPC_{t+1} = \sum_{i=1}^{M} \Delta mpc_{t+1}^i. \tag{A.37}$$

$$\bar{C}_{t+1}^i = \begin{cases} (1 + x + \Delta mpc_{t+1}^i) Y_{t+1}^i & \text{optimist,} \\ Y_{t+1}^i & \text{stable agent,} \\ (1 - x + \Delta mpc_{t+1}^i) Y_{t+1}^i & \text{pessimist.} \end{cases} \tag{A.38}$$

$$ID^i_{t+1} = \max\left\{C^0; \gamma C^i_t + (1-\gamma)\bar{C}^i_{t+1}\right\}. \tag{A.39}$$

$$AD_{t+1} = \sum_{i=1}^{M} ID^i_{t+1}. \tag{A.40}$$

$$AS_{t+1} = Q_{t+1} + I_{t+1}. \tag{A.41}$$

$$L^2_{t+1} = \frac{1}{\nu} L^1_{t+1}. \tag{A.42}$$

$$L_{t+1} = L^1_{t+1} + L^2_{t+1} = L^1_{t+1}\left(1 + \frac{1}{\nu}\right). \tag{A.43}$$

$$U_{t+1} = M - L_{t+1}. \tag{A.44}$$

$$Q_{t+1} = a^L L^1_{t+1}. \tag{A.45}$$

$$\bar{L}^1_{t+1} = \frac{\bar{Q}_{t+1}}{a^L}. \tag{A.46}$$

$$L^2_{t+1} = \left\lfloor \frac{\bar{L}^1_{t+1}}{\nu} \right\rfloor, \tag{A.47}$$

$$Y_{t+1} = Q_{t+1}. \tag{A.48}$$

$$W^2_{t+1} = bW^1_{t+1}. \tag{A.49}$$

$$SC_{t+1} = \omega^U W^1_{t+1}. \tag{A.50}$$

$$Y^i_{t+1} = \begin{cases} W^1_{t+1} & \text{for the 1st-tier workers,} \\ W^2_{t+1} & \text{for the 2nd-tier workers,} \\ SC_{t+1} & \text{for the unemployed.} \end{cases} \tag{A.51}$$

$$Y_{t+1} = L^1_{t+1}W^1_{t+1} + L^2_{t+1}W^2_{t+1} + U_{t+1}SC_{t+1}. \tag{A.52}$$

$$W^1_{t+1} = \frac{Y_{t+1}}{\omega^U U_{t+1} + L^1_{t+1} + bL^2_{t+1}}. \tag{A.53}$$

$$EQ_{t+1} = \min\{AD_{t+1}, AS_{t+1}\}. \tag{A.54}$$

$$EQ_{t+1} = C_{t+1}. \tag{A.55}$$

$$C^i_{t+1} = C_{t+1}\frac{ID^i_{t+1}}{AD_{t+1}}. \tag{A.56}$$

$$S^i_{t+1} = Y^i_{t+1} - C^i_{t+1}, \tag{A.57}$$

$$S_{t+1} = \sum_{i=1}^{M} S^i_{t+1} = Y_{t+1} - C_{t+1}. \tag{A.58}$$

$$A^i_{t+1} = A^i_t + S^i_{t+1}, \tag{A.59}$$

$$A_{t+1} = \sum_{i=1}^{M} A^i_{t+1} = A_t + S_{t+1}. \tag{A.60}$$

$$I_{t+2} = AS_{t+1} - EQ_{t+1}. \tag{A.61}$$

A.4 The code of the baseline model (used also for sensitivity analysis)

```
#  ACE model in the spirit of Westerhoff, with the demand versus supply structure
#        written by Jana Zavacka, March 2014 Ca Foscari Venice
###############################################################

getwd()
setwd("C:/Users/zav0032/Desktop/ACE model/Rscripts_ACE")
#source("ACE_stableR1.R")
# LIBRARIES TO USE
# firstly the library packages for heating maps are controlled or installed
# library()
#.libPaths()
#chooseCRANmirror()
#install.packages()
rm(list=ls())
#load("C:/Users/zav0032/Desktop/ACE model/Rscripts_ACE/ACE_stableR1v2.RData")
library(ggplot2)
library(grid)
library(gridExtra)
#dev.off()              #some tip to overcome error of graphics???
#require(....
require(gridExtra);require(reshape2);require(ggplot2)
#library(simecol)

# PARAMETER SETTING
M<-1600
#10000
x<-0.1
#0.1
alpha_y<-0.5
#5
alpha_s<- -0.15
# -0.10
beta<-1-alpha_y
#1
gamma<-0.55
#0.8
C0<-0.6 #minimal consumption
kappa<-1        #melting parameter of inventories
#0.6
delta<-0         #weight by the sticky growth rate of production
#0.7
lmax<-1   #maximum labor employment, full time employment of one agent=1
TT<-300                                                           #time horizon for macro steps
#300
T<-1600                                                           #time horizon for micro steps
#10000
TTT<-1   #number of runs of model
PT<-0  #grid for parameter sensitivity
drop<-50

# STORE VARIABLES DEFINITION
statYY<-array(0,c(7,PT+1))
statyy_growth<-array(0,c(7,PT+1))
statCC<-array(0,c(7,PT+1))
statcc_growth<-array(0,c(7,PT+1))
#CCi<-array(0,c(sqrt(M),sqrt(M),TT,TTT,PT+1))  #individual consumption spending
statSS<-array(0,c(7,PT+1))
```

```
statAA<-array(0,c(7,PT+1))
statWWEALTH<-array(0,c(7,PT+1))
statAAD<-array(0,c(7,PT+1))
#AADi<-array(0,c(sqrt(M),sqrt(M),TT,TTT,PT+1))
statQQ<-array(0,c(7,PT+1))
statII<-array(0,c(7,PT+1))
statAAS<-array(0,c(7,PT+1))
statEEQ<-array(0,c(7,PT+1))
statOO<-array(0,c(7,PT+1))
statPP<-array(0,c(7,PT+1))
statSST<-array(0,c(7,PT+1))
statCCONF<-array(0,c(7,PT+1))
statlllengthBCexp<-array(0,c(7,PT+1))
statlllengthBCcontr<-array(0,c(7,PT+1))
statlllengthBC<-array(0,c(7,PT+1))
statlllamplitudeBCexp<-array(0,c(7,PT+1))
statlllamplitudeBCcontr<-array(0,c(7,PT+1))
statBCcount<-array(0,c(7,PT+1))

tstatYY<-array(0,c(TT-drop,7,PT+1))
tstatyy_growth<-array(0,c(TT-drop,7,PT+1))
tstatCC<-array(0,c(TT-drop,7,PT+1))
tstatcc_growth<-array(0,c(TT-drop,7,PT+1))
#CCi<-array(0,c(sqrt(M),sqrt(M),TT-drop,TTT,PT+1))  #individual consumption spending
tstatSS<-array(0,c(TT-drop,7,PT+1))
tstatAA<-array(0,c(TT-drop,7,PT+1))
tstatWWEALTH<-array(0,c(TT-drop,7,PT+1))
tstatAAD<-array(0,c(TT-drop,7,PT+1))
#AADi<-array(0,c(sqrt(M),sqrt(M),TT-drop,TTT,PT+1))
tstatQQ<-array(0,c(TT-drop,7,PT+1))
tstatII<-array(0,c(TT-drop,7,PT+1))
tstatAAS<-array(0,c(TT-drop,7,PT+1))
tstatEEQ<-array(0,c(TT-drop,7,PT+1))
tstatOO<-array(0,c(TT-drop,7,PT+1))
tstatPP<-array(0,c(TT-drop,7,PT+1))
tstatSST<-array(0,c(TT-drop,7,PT+1))
tstatCCONF<-array(0,c(TT-drop,7,PT+1))

bpYY<-array(0,c(TTT,PT+1))
bplllengthBCexp<-array(0,c(TTT,PT+1))
bplllengthBCcontr<-array(0,c(TTT,PT+1))
bplllengthBC<-array(0,c(TTT,PT+1))
bplllamplitudeBCexp<-array(0,c(TTT,PT+1))
bplllamplitudeBCcontr<-array(0,c(TTT,PT+1))
bpBCcount<-array(0,c(TTT,PT+1))

pt<-1
#pt<-pt+1
#for (pt in 1:(PT+1)){

#  alpha_y<-0+(pt-1)*1/PT
#  beta<-1-alpha_y

  #variables to store results from simulation runs for statistic evaluation
  YY<-array(0,c(TT-drop,TTT))
  yy_growth<-array(0,c(TT-drop,TTT))
  CC<-array(0,c(TT-drop,TTT))
  cc_growth<-array(0,c(TT-drop,TTT))
  #CCi<-array(0,c(sqrt(M),sqrt(M),TT-drop,TTT,PT+1))  #individual consumption spending
```

```
 SS<-array(0,c(TT-drop,TTT))
 AA<-array(0,c(TT-drop,TTT))
 WWEALTH<-array(0,c(TT-drop,TTT))
 AAD<-array(0,c(TT-drop,TTT))
 #AADi<-array(0,c(sqrt(M),sqrt(M),TT-drop,TTT,PT+1))
 QQ<-array(0,c(TT-drop,TTT))
 II<-array(0,c(TT-drop,TTT))
 AAS<-array(0,c(TT-drop,TTT))
 EEQ<-array(0,c(TT-drop,TTT))
 OO<-array(0,c(TT-drop,TTT))
 PP<-array(0,c(TT-drop,TTT))
 SST<-array(0,c(TT-drop,TTT))
 CCONF<-array(0,c(TT-drop,TTT))
 llengthBCexp<-array(0,c((TT-drop)*TTT))  #maximal length
 llengthBCcontr<-array(0,c((TT-drop)*TTT))
 llengthBC<-array(0,c((TT-drop)*TTT))
 aamplitudeBCexp<-array(0,c((TT-drop)*TTT))
 aamplitudeBCcontr<-array(0,c((TT-drop)*TTT))
 lll<-0
 BCcount<-array(0,c(TTT))

r<-1
# r<-r+1

# for (r in 1:TTT){

   # VARIABLES DEFINITION + INITIAL SETTING
   Y<-array(0,c(TT))
   Y_mean<-array(0,c(TT))
   y_growth<-array(0,c(TT))
   C<-array(0,c(TT))
   c_growth<-array(0,c(TT))
   Ci<-array(0,c(sqrt(M),sqrt(M),TT))  #individual consumption spending
   S<-array(0,c(TT))
   A<-array(0,c(TT))
   WEALTH<-array(0,c(TT))
   AD<-array(0,c(TT))
   ADi<-array(0,c(sqrt(M),sqrt(M),TT))
   Q<-array(0,c(TT))
   I<-array(0,c(TT))
   AS<-array(0,c(TT))
   EQ<-array(0,c(TT))
   Alpha_y<-array(0,c(TT))
   Alpha_s<-array(0,c(TT))
   MPC<-array(0,c(TT))
   O<-array(0,c(TT))
   P<-array(0,c(TT))
   ST<-array(0,c(TT))
   CONF<-array(0,c(TT))
   lengthBCexp<-array(0,c(TT))
   lengthBCcontr<-array(0,c(TT))
   lengthBC<-array(0,c(TT))
   amplitudeBCexp<-array(0,c(TT))
   amplitudeBCcontr<-array(0,c(TT))

   randomset<-sample(1:M,2*trunc(M/3),replace=F)
   MOOD<-array(0,c(sqrt(M),sqrt(M),TT))                    #matrix of optimists in macro step
   mpc<-array(0,c(sqrt(M),sqrt(M),TT))
   #for (i in 1:(2*trunc(M/3))){
```

```
#MOOD[,,1]<-0   # for steady state
#optimistic/pessimistic shock
for (i in 1:(trunc(M/2))){
    m<-randomset[i]/sqrt(M)
    n<-randomset[i]%%(sqrt(M))
    ifelse(n==0,n<-sqrt(M),m<-m+1)
  ifelse(i<=trunc(M/2),MOOD[m,n,1]<-1,MOOD[m,n,1]<-0)
}
MOODmicro<-MOOD[,,1]
MOODmelt<-melt(MOODmicro)                                   #melted matrix of optimists
names(MOODmelt)=c("x","y",paste("t",1,sep=""))
#Alpha_y[1]<- alpha_y

# THE STARTING POINT - is set for 6% unemployment,
#with half of optimists and half of stable agents, all income is consumed,
# the amount of inventory is equal to the HH assets.
Alpha_y[1]<- 0
Alpha_s[1]<- 0
mpc[,,1]<-0
C[1]<-0.94*M
c_growth[1]<-0
A[1]<-0.94*M
Q[1]<-0.94*M
I[1]<-0.94*M
Y[1]<-Q[1]
S[1]<-Y[1]-C[1]
WEALTH[1]<-A[1]+Y[1]
y_mean<-Y[1]
AS[1]<-Q[1]+I[1]
AD[1]<-C[1]
EQ[1]<-min(AD[1],AS[1])
O[1]<-(sum(abs(MOOD[,,1])+MOOD[,,1]))/2
P[1]<-sum(abs(MOOD[,,1]))-O[1]
ST[1]<-M-O[1]-P[1]
CONF[1]<-O[1]-P[1]

# SIMULATIONS for one run r
for (t in 1:(TT-1)){                        #macro step
#  for (t in 1:(19)){                        #macro step
#   cat("thid is time: ",t)
#   browser()
    MOODmicro<-MOOD[,,t]
    for (tau in 1:T){                                                    #micro step
            i<-sample(1:sqrt(M),2,replace=T)                   #random choose of the firm i
           m<-i[1]                                             #the m row of ith firm
            n<-i[2]                                            #the n column of ith firm
            Neighbours=MOODmicro[sqrt(M)-(sqrt(M)-(m-1))%%(sqrt(M)),n]+
                        +MOODmicro[m,sqrt(M)-(sqrt(M)-(n-1))%%(sqrt(M))]+
                        +MOODmicro[m%%(sqrt(M))+1,n]+
                        +MOODmicro[m,n%%(sqrt(M))+1]
  #toto jiy funguje
#      betamicro<-beta*Neighbours
#      ProbP<-1/(1+exp(Alpha_y[t]+betamicro))
#      ProbO<-(1-ProbP)
#      Optimist<-rbinom(1,1,ProbO)
#      ifelse(Optimist>0,MOODmicro[m,n]<-1,MOODmicro[m,n]<--1)
#      if (Alpha_y[t]==0 && Neighbours==0){MOODmicro[m,n]<-0}

    # alternative
```

```
            Persuasivness<-alpha_y*Alpha_y[t]+beta*Neighbours/4
            ifelse(Persuasivness>-1/3,ifelse(Persuasivness>1/3,
    MOODmicro[m,n]<-1,MOODmicro[m,n]<-0),MOODmicro[m,n]<- -1)
    ###
  }
  MOOD[,,t+1]<-MOODmicro                      #save the matrix of optimists at time t+1
  MOODmicro_melted<-melt(MOODmicro)
  names(MOODmicro_melted)<-c("x","y",paste("t",t+1,sep=""))
  MOODmicro_melted$x<-NULL
  MOODmicro_melted$y<-NULL
  MOODmelt<-cbind(MOODmelt,MOODmicro_melted)  #add a melted vector to matrix
  O[t+1]<-(sum(abs(MOOD[,,t+1])+MOOD[,,t+1]))/2   #counts the number of optimists
  P[t+1]<-sum(abs(MOOD[,,t+1]))-O[t+1]
 ST[t+1]<-M-O[t+1]-P[t+1]
 CONF[t+1]<-O[t+1]-P[t+1]
  #the condition of nonnegative production:

 #the rests after previous period
  I[t+1]<-AS[t]-EQ[t]
  A[t+1]<-A[t]+S[t]

 # firms behavior
#  Q[t+1]<-delta*Q[t]+(1-delta)*max(EQ[t]-kappa*I[t+1],(1+X*(O[t+1]-P[t+1])/M)*Q[t])
#  Q[t+1]<-max(0,delta*Q[t]+(1-delta)*(2*min(lmax*M,EQ[t])-kappa*I[t+1]))
 Q[t+1]<-max(0,delta*Q[t]+(1-delta)*(min(lmax*M,2*EQ[t]-kappa*I[t+1])))

# Q is a function of labor, maximum employment is lmax*M
 AS[t+1]<-Q[t+1]+I[t+1]
 Y[t+1]<-Q[t+1]
 y_growth[t+1]<-Y[t+1]/Y[t]-1
 WEALTH[t+1]<-A[t+1]+Y[t+1]

  # HH behavior
  #  C[t+1]<-max(Cmin,(1+X*(O[t+1]-P[t+1])/M)*Y[t])
  #  C[t+1]<-(1+X*(O[t+1]-P[t+1])/M)*Y[t]
  #  C[t+1]<-gamma*C[t]+(1-gamma)*(1+X*(O[t]-P[t])/M)*Y[t]
 for (m in 1:sqrt(M)){
  for (n in 1:sqrt(M)){
   if(MOOD[m,n,t+1]==1){
    ifelse((MOOD[m,n,t-3]+MOOD[m,n,t-2]+MOOD[m,n,t-1]+MOOD[m,n,t]+MOOD[m,n,t+1]==5),
    mpc[m,n,t+1]<-alpha_s,mpc[m,n,t+1]<-mpc[m,n,t])
    ifelse(MOOD[m,n,t]==-1,mpc[m,n,t+1]<-0,empty<-0)
    ADi[m,n,t+1]<-max(C0,gamma*Ci[m,n,t]+(1-gamma)*(1+x+mpc[m,n,t+1])*Y[t+1]/M)
   }else if(MOOD[m,n,t+1]==0){
    mpc[m,n,t+1]<-0
    ADi[m,n,t+1]<-max(C0,gamma*Ci[m,n,t]+(1-gamma)*(1+mpc[m,n,t+1])*Y[t+1]/M)
   }else {
    ifelse((MOOD[m,n,t-3]+MOOD[m,n,t-2]+MOOD[m,n,t-1]+MOOD[m,n,t]+MOOD[m,n,t+1]==-5),
    mpc[m,n,t+1]<- - alpha_s,mpc[m,n,t+1]<-mpc[m,n,t])
    ifelse(MOOD[m,n,t]==1,mpc[m,n,t+1]<-0,empty<-0)
    ADi[m,n,t+1]<-max(C0,gamma*Ci[m,n,t]+(1-gamma)*(1-x+mpc[m,n,t+1])*Y[t+1]/M)
   }
  }
 }
#   ifelse(t>3,C[t+1]<-gamma*C[t]+(1-gamma)*(1+X*(O[t+1]-P[t+1])/M)*(Y[t-2]+Y[t-1]+Y[t]+Y[t+1])/4,
C[t+1]<-gamma*C[t]+(1-gamma)*(1+X*(O[t+1]-P[t+1])/M)*Y[t+1])

  AD[t+1]<-sum(ADi[,,t+1])
 MPC[t+1]<-sum(mpc[,,t+1])
```

```
    #market equilibrium
    EQ[t+1]=min(AS[t+1],AD[t+1])

    # HH
    C[t+1]<-EQ[t+1]
    c_growth[t+1]<-C[t+1]/C[t]-1
    for (m in 1:sqrt(M)){
      for (n in 1:sqrt(M)){
        ifelse(AD[t+1]>0,Ci[m,n,t+1]<-ADi[m,n,t+1]*EQ[t+1]/AD[t+1],0)
      }
    }
    S[t+1]<-Y[t+1]-EQ[t+1]

  # NEW PARAMETER SETTING
    ifelse(Y[t+1]>=Y[t],ifelse(Y[t+1]>Y[t],Alpha_y[t+1]<-1,Alpha_y[t+1]<-0),Alpha_y[t+1]<--1)
  #   ifelse(Y[t+1]>=Y[t],Alpha_y[t+1]<-1,Alpha_y[t+1]<--1)

  } #the end of one run

  YY[,r]<-tail(Y,TT-drop)
  yy_growth[,r]<-tail(y_growth,TT-drop)
  CC[,r]<-tail(C,TT-drop)
  cc_growth[,r]<-tail(c_growth,TT-drop)
#    CCi[,,,r]<-Ci[,,]
  SS[,r]<-tail(S,TT-drop)
  AA[,r]<-tail(A,TT-drop)
  WWEALTH[,r]<-tail(WEALTH,TT-drop)
  AAD[,r]<-tail(AD,TT-drop)
#    AADi[,,,r]<-ADi[,,]
  QQ[,r]<-tail(Q,TT-drop)
  II[,r]<-tail(I,TT-drop)
  AAS[,r]<-tail(AS,TT-drop)
  EEQ[,r]<-tail(EQ,TT-drop)
  OO[,r]<-tail(O,TT-drop)
  PP[,r]<-tail(P,TT-drop)
  SST[,r]<-tail(ST,TT-drop)
  CCONF[,r]<-tail(CONF,TT-drop)


  BCexp<-1  #not important, the first BC will be dropped anyway
  ll<-1
  for (bct in (drop+1):TT){
    if(BCexp==1){
      ifelse(y_growth[bct]<0,BCexp<-0,lengthBCexp[ll]<-lengthBCexp[ll]+1)
      ifelse(BCexp==0,lengthBCcontr[ll]<-lengthBCcontr[ll]+1,l<-0)
      ifelse(BCexp==0,amplitudeBCexp[ll]<-Y[bct-1]-amplitudeBCexp[ll],l<-0)
      #     ifelse(BCexp==0,amplitudeBCexp[ll]<-Y[bct-1]-amplitudeBCexp[ll],l<-0)
      ifelse(BCexp==0,amplitudeBCcontr[ll]<-Y[bct-1],l<-0)
    } else {
      ifelse(y_growth[bct]>0,BCexp<-1,lengthBCcontr[ll]<-lengthBCcontr[ll]+1)
      ifelse(BCexp==1,amplitudeBCcontr[ll]<-amplitudeBCcontr[ll]-Y[bct-1],l<-0)
      ifelse(BCexp==1,ll<-ll+1,l<-0)
      ifelse(BCexp==1,lengthBCexp[ll]<-lengthBCexp[ll]+1,l<-0)
      ifelse(BCexp==1,amplitudeBCexp[ll]<-Y[bct-1],l<-0)
    }
  }
  if (ll>2){
    for (k in 1:(ll-2)){
      llengthBCexp[lll+k]<-lengthBCexp[k+1]
```

```
      llengthBCcontr[lll+k]<-lengthBCcontr[k+1]
      llengthBC[lll+k]<-lengthBCexp[k+1]+lengthBCcontr[k+1]
      aamplitudeBCexp[lll+k]<-amplitudeBCexp[k+1]
      aamplitudeBCcontr[lll+k]<-amplitudeBCcontr[k+1]
    }
    lll<-lll+ll-2
  } else {
    lll<-lll
  }
  ifelse(ll>2,BCcount[r]<-ll-2,BCcount[r]<-ll-1)

  bpYY[r,pt]<-mean(YY[,r])
  if (ll>2){
    sumbplllengthBCexp<-0
    sumbplllengthBCcontr<-0
    sumbplllengthBC<-0
    sumbplllamplitudeBCexp<-0
    sumbplllamplitudeBCcontr<-0
    for (k in 1:(ll-2)){
      sumbplllengthBCexp<-sumbplllengthBCexp+lengthBCexp[k+1]
      sumbplllengthBCcontr<-sumbplllengthBCcontr+lengthBCcontr[k+1]
      sumbplllengthBC<-sumbplllengthBC+lengthBCexp[k+1]+lengthBCcontr[k+1]
      sumbplllamplitudeBCexp<-sumbplllamplitudeBCexp+amplitudeBCexp[k+1]
      sumbplllamplitudeBCcontr<-sumbplllamplitudeBCcontr+amplitudeBCcontr[k+1]
    }
    bplllengthBCexp[r,pt]<-sumbplllengthBCexp/(ll-2) #save the average value of the length BC in this run
    bplllengthBCcontr[r,pt]<-sumbplllengthBCcontr/(ll-2)
    bplllengthBC[r,pt]<-sumbplllengthBC/(ll-2)
    bplllamplitudeBCexp[r,pt]<-sumbplllamplitudeBCexp/(ll-2)
    bplllamplitudeBCcontr[r,pt]<-sumbplllamplitudeBCcontr/(ll-2)
  } else {
    bplllengthBCexp[r,pt]<-0
    bplllengthBCcontr[r,pt]<-0
    bplllengthBC[r,pt]<-0
    bplllamplitudeBCexp[r,pt]<-0
    bplllamplitudeBCcontr[r,pt]<-0
  }
  bpBCcount[r,pt]<-BCcount[r]

#  } #the end of all runs for one fixed parameter


 for (t in 1:(TT-drop)){

  tstatYY[t,1,pt]<-mean(YY[t,])
  tstatYY[t,2,pt]<-sd(YY[t,])
  tstatYY[t,3,pt]<-median(YY[t,])
  tstatYY[t,4,pt]<-min(YY[t,])
  tstatYY[t,5,pt]<-max(YY[t,])
  tstatYY[t,6,pt]<-quantile(YY[t,],c(0.25), type = 1)
  tstatYY[t,7,pt]<-quantile(YY[t,],c(0.75), type = 1)
  #summary(YY[t,])
  tstatyy_growth[t,1,pt]<-mean(yy_growth[t,])
  tstatyy_growth[t,2,pt]<-sd(yy_growth[t,])
  tstatyy_growth[t,3,pt]<-median(yy_growth[t,])
  tstatyy_growth[t,4,pt]<-min(yy_growth[t,])
  tstatyy_growth[t,5,pt]<-max(yy_growth[t,])
  tstatyy_growth[t,6,pt]<-quantile(yy_growth[t,],c(0.25), type = 1)
  tstatyy_growth[t,7,pt]<-quantile(yy_growth[t,],c(0.75), type = 1)
```

```
tstatCC[t,1,pt]<-mean(CC[t,])
tstatCC[t,2,pt]<-sd(CC[t,])
tstatCC[t,3,pt]<-median(CC[t,])
tstatCC[t,4,pt]<-min(CC[t,])
tstatCC[t,5,pt]<-max(CC[t,])
tstatCC[t,6,pt]<-quantile(CC[t,],c(0.25), type = 1)
tstatCC[t,7,pt]<-quantile(CC[t,],c(0.75), type = 1)

tstatcc_growth[t,1,pt]<-mean(cc_growth[t,])
tstatcc_growth[t,2,pt]<-sd(cc_growth[t,])
tstatcc_growth[t,3,pt]<-median(cc_growth[t,])
tstatcc_growth[t,4,pt]<-min(cc_growth[t,])
tstatcc_growth[t,5,pt]<-max(cc_growth[t,])
tstatcc_growth[t,6,pt]<-quantile(cc_growth[t,],c(0.25), type = 1)
tstatcc_growth[t,7,pt]<-quantile(cc_growth[t,],c(0.75), type = 1)

tstatSS[t,1,pt]<-mean(SS[t,])
tstatSS[t,2,pt]<-sd(SS[t,])
tstatSS[t,3,pt]<-median(SS[t,])
tstatSS[t,4,pt]<-min(SS[t,])
tstatSS[t,5,pt]<-max(SS[t,])
tstatSS[t,6,pt]<-quantile(SS[t,],c(0.25), type = 1)
tstatSS[t,7,pt]<-quantile(SS[t,],c(0.75), type = 1)

tstatAA[t,1,pt]<-mean(AA[t,])
tstatAA[t,2,pt]<-sd(AA[t,])
tstatAA[t,3,pt]<-median(AA[t,])
tstatAA[t,4,pt]<-min(AA[t,])
tstatAA[t,5,pt]<-max(AA[t,])
tstatAA[t,6,pt]<-quantile(AA[t,],c(0.25), type = 1)
tstatAA[t,7,pt]<-quantile(AA[t,],c(0.75), type = 1)

tstatWWEALTH[t,1,pt]<-mean(WWEALTH[t,])
tstatWWEALTH[t,2,pt]<-sd(WWEALTH[t,])
tstatWWEALTH[t,3,pt]<-median(WWEALTH[t,])
tstatWWEALTH[t,4,pt]<-min(WWEALTH[t,])
tstatWWEALTH[t,5,pt]<-max(WWEALTH[t,])
tstatWWEALTH[t,6,pt]<-quantile(WWEALTH[t,],c(0.25), type = 1)
tstatWWEALTH[t,7,pt]<-quantile(WWEALTH[t,],c(0.75), type = 1)

tstatAAD[t,1,pt]<-mean(AAD[t,])
tstatAAD[t,2,pt]<-sd(AAD[t,])
tstatAAD[t,3,pt]<-median(AAD[t,])
tstatAAD[t,4,pt]<-min(AAD[t,])
tstatAAD[t,5,pt]<-max(AAD[t,])
tstatAAD[t,6,pt]<-quantile(AAD[t,],c(0.25), type = 1)
tstatAAD[t,7,pt]<-quantile(AAD[t,],c(0.75), type = 1)

tstatQQ[t,1,pt]<-mean(QQ[t,])
tstatQQ[t,2,pt]<-sd(QQ[t,])
tstatQQ[t,3,pt]<-median(QQ[t,])
tstatQQ[t,4,pt]<-min(QQ[t,])
tstatQQ[t,5,pt]<-max(QQ[t,])
tstatQQ[t,6,pt]<-quantile(QQ[t,],c(0.25), type = 1)
tstatQQ[t,7,pt]<-quantile(QQ[t,],c(0.75), type = 1)

tstatII[t,1,pt]<-mean(II[t,])
tstatII[t,2,pt]<-sd(II[t,])
```

```
    tstatII[t,3,pt]<-median(II[t,])
    tstatII[t,4,pt]<-min(II[t,])
    tstatII[t,5,pt]<-max(II[t,])
    tstatII[t,6,pt]<-quantile(II[t,],c(0.25), type = 1)
    tstatII[t,7,pt]<-quantile(II[t,],c(0.75), type = 1)

    tstatAAS[t,1,pt]<-mean(AAS[t,])
    tstatAAS[t,2,pt]<-sd(AAS[t,])
    tstatAAS[t,3,pt]<-median(AAS[t,])
    tstatAAS[t,4,pt]<-min(AAS[t,])
    tstatAAS[t,5,pt]<-max(AAS[t,])
    tstatAAS[t,6,pt]<-quantile(AAS[t,],c(0.25), type = 1)
    tstatAAS[t,7,pt]<-quantile(AAS[t,],c(0.75), type = 1)

    tstatEEQ[t,1,pt]<-mean(EEQ[t,])
    tstatEEQ[t,2,pt]<-sd(EEQ[t,])
    tstatEEQ[t,3,pt]<-median(EEQ[t,])
    tstatEEQ[t,4,pt]<-min(EEQ[t,])
    tstatEEQ[t,5,pt]<-max(EEQ[t,])
    tstatEEQ[t,6,pt]<-quantile(EEQ[t,],c(0.25), type = 1)
    tstatEEQ[t,7,pt]<-quantile(EEQ[t,],c(0.75), type = 1)

    tstatOO[t,1,pt]<-mean(OO[t,])
    tstatOO[t,2,pt]<-sd(OO[t,])
    tstatOO[t,3,pt]<-median(OO[t,])
    tstatOO[t,4,pt]<-min(OO[t,])
    tstatOO[t,5,pt]<-max(OO[t,])
    tstatOO[t,6,pt]<-quantile(OO[t,],c(0.25), type = 1)
    tstatOO[t,7,pt]<-quantile(OO[t,],c(0.75), type = 1)

    tstatPP[t,1,pt]<-mean(PP[t,])
    tstatPP[t,2,pt]<-sd(PP[t,])
    tstatPP[t,3,pt]<-median(PP[t,])
    tstatPP[t,4,pt]<-min(PP[t,])
    tstatPP[t,5,pt]<-max(PP[t,])
    tstatPP[t,6,pt]<-quantile(PP[t,],c(0.25), type = 1)
    tstatPP[t,7,pt]<-quantile(PP[t,],c(0.75), type = 1)

    tstatSST[t,1,pt]<-mean(SST[t,])
    tstatSST[t,2,pt]<-sd(SST[t,])
    tstatSST[t,3,pt]<-median(SST[t,])
    tstatSST[t,4,pt]<-min(SST[t,])
    tstatSST[t,5,pt]<-max(SST[t,])
    tstatSST[t,6,pt]<-quantile(SST[t,],c(0.25), type = 1)
    tstatSST[t,7,pt]<-quantile(SST[t,],c(0.75), type = 1)

    tstatCCONF[t,1,pt]<-mean(CCONF[t,])
    tstatCCONF[t,2,pt]<-sd(CCONF[t,])
    tstatCCONF[t,3,pt]<-median(CCONF[t,])
    tstatCCONF[t,4,pt]<-min(CCONF[t,])
    tstatCCONF[t,5,pt]<-max(CCONF[t,])
    tstatCCONF[t,6,pt]<-quantile(CCONF[t,],c(0.25), type = 1)
    tstatCCONF[t,7,pt]<-quantile(CCONF[t,],c(0.75), type = 1)


}
statYY[1,pt]<-mean(YY)
statYY[2,pt]<-sd(YY)
statYY[3,pt]<-median(YY)
```

```
statYY[4,pt]<-min(YY)
statYY[5,pt]<-max(YY)
statYY[6,pt]<-quantile(YY,c(0.25), type = 1)
statYY[7,pt]<-quantile(YY,c(0.75), type = 1)
#summary(YY)
statyy_growth[1,pt]<-mean(yy_growth)
statyy_growth[2,pt]<-sd(yy_growth)
statyy_growth[3,pt]<-median(yy_growth)
statyy_growth[4,pt]<-min(yy_growth)
statyy_growth[5,pt]<-max(yy_growth)
statyy_growth[6,pt]<-quantile(yy_growth,c(0.25), type = 1)
statyy_growth[7,pt]<-quantile(yy_growth,c(0.75), type = 1)

statCC[1,pt]<-mean(CC)
statCC[2,pt]<-sd(CC)
statCC[3,pt]<-median(CC)
statCC[4,pt]<-min(CC)
statCC[5,pt]<-max(CC)
statCC[6,pt]<-quantile(CC,c(0.25), type = 1)
statCC[7,pt]<-quantile(CC,c(0.75), type = 1)

statcc_growth[1,pt]<-mean(cc_growth)
statcc_growth[2,pt]<-sd(cc_growth)
statcc_growth[3,pt]<-median(cc_growth)
statcc_growth[4,pt]<-min(cc_growth)
statcc_growth[5,pt]<-max(cc_growth)
statcc_growth[6,pt]<-quantile(cc_growth,c(0.25), type = 1)
statcc_growth[7,pt]<-quantile(cc_growth,c(0.75), type = 1)

statSS[1,pt]<-mean(SS)
statSS[2,pt]<-sd(SS)
statSS[3,pt]<-median(SS)
statSS[4,pt]<-min(SS)
statSS[5,pt]<-max(SS)
statSS[6,pt]<-quantile(SS,c(0.25), type = 1)
statSS[7,pt]<-quantile(SS,c(0.75), type = 1)

statAA[1,pt]<-mean(AA)
statAA[2,pt]<-sd(AA)
statAA[3,pt]<-median(AA)
statAA[4,pt]<-min(AA)
statAA[5,pt]<-max(AA)
statAA[6,pt]<-quantile(AA,c(0.25), type = 1)
statAA[7,pt]<-quantile(AA,c(0.75), type = 1)

statWWEALTH[1,pt]<-mean(WWEALTH)
statWWEALTH[2,pt]<-sd(WWEALTH)
statWWEALTH[3,pt]<-median(WWEALTH)
statWWEALTH[4,pt]<-min(WWEALTH)
statWWEALTH[5,pt]<-max(WWEALTH)
statWWEALTH[6,pt]<-quantile(WWEALTH,c(0.25), type = 1)
statWWEALTH[7,pt]<-quantile(WWEALTH,c(0.75), type = 1)

statAAD[1,pt]<-mean(AAD)
statAAD[2,pt]<-sd(AAD)
statAAD[3,pt]<-median(AAD)
statAAD[4,pt]<-min(AAD)
statAAD[5,pt]<-max(AAD)
statAAD[6,pt]<-quantile(AAD,c(0.25), type = 1)
```

```
statAAD[7,pt]<-quantile(AAD,c(0.75), type = 1)

statQQ[1,pt]<-mean(QQ)
statQQ[2,pt]<-sd(QQ)
statQQ[3,pt]<-median(QQ)
statQQ[4,pt]<-min(QQ)
statQQ[5,pt]<-max(QQ)
statQQ[6,pt]<-quantile(QQ,c(0.25), type = 1)
statQQ[7,pt]<-quantile(QQ,c(0.75), type = 1)

statII[1,pt]<-mean(II)
statII[2,pt]<-sd(II)
statII[3,pt]<-median(II)
statII[4,pt]<-min(II)
statII[5,pt]<-max(II)
statII[6,pt]<-quantile(II,c(0.25), type = 1)
statII[7,pt]<-quantile(II,c(0.75), type = 1)

statAAS[1,pt]<-mean(AAS)
statAAS[2,pt]<-sd(AAS)
statAAS[3,pt]<-median(AAS)
statAAS[4,pt]<-min(AAS)
statAAS[5,pt]<-max(AAS)
statAAS[6,pt]<-quantile(AAS,c(0.25), type = 1)
statAAS[7,pt]<-quantile(AAS,c(0.75), type = 1)

statEEQ[1,pt]<-mean(EEQ)
statEEQ[2,pt]<-sd(EEQ)
statEEQ[3,pt]<-median(EEQ)
statEEQ[4,pt]<-min(EEQ)
statEEQ[5,pt]<-max(EEQ)
statEEQ[6,pt]<-quantile(EEQ,c(0.25), type = 1)
statEEQ[7,pt]<-quantile(EEQ,c(0.75), type = 1)

statOO[1,pt]<-mean(OO)
statOO[2,pt]<-sd(OO)
statOO[3,pt]<-median(OO)
statOO[4,pt]<-min(OO)
statOO[5,pt]<-max(OO)
statOO[6,pt]<-quantile(OO,c(0.25), type = 1)
statOO[7,pt]<-quantile(OO,c(0.75), type = 1)

statPP[1,pt]<-mean(PP)
statPP[2,pt]<-sd(PP)
statPP[3,pt]<-median(PP)
statPP[4,pt]<-min(PP)
statPP[5,pt]<-max(PP)
statPP[6,pt]<-quantile(PP,c(0.25), type = 1)
statPP[7,pt]<-quantile(PP,c(0.75), type = 1)

statSST[1,pt]<-mean(SST)
statSST[2,pt]<-sd(SST)
statSST[3,pt]<-median(SST)
statSST[4,pt]<-min(SST)
statSST[5,pt]<-max(SST)
statSST[6,pt]<-quantile(SST,c(0.25), type = 1)
statSST[7,pt]<-quantile(SST,c(0.75), type = 1)

statCCONF[1,pt]<-mean(CCONF)
```

```
statCCONF[2,pt]<-sd(CCONF)
statCCONF[3,pt]<-median(CCONF)
statCCONF[4,pt]<-min(CCONF)
statCCONF[5,pt]<-max(CCONF)
statCCONF[6,pt]<-quantile(CCONF,c(0.25), type = 1)
statCCONF[7,pt]<-quantile(CCONF,c(0.75), type = 1)

if(lll>0){
  lllengthBCexp<-array(0,c(lll))
  lllengthBCcontr<-array(0,c(lll))
  lllengthBC<-array(0,c(lll))
  lllamplitudeBCexp<-array(0,c(lll))
  lllamplitudeBCcontr<-array(0,c(lll))
  for (j in 1:lll){
    lllengthBCexp[j]<-llengthBCexp[j]
    lllengthBCcontr[j]<-llengthBCcontr[j]
    lllengthBC[j]<-llengthBC[j]
    lllamplitudeBCexp[j]<-aamplitudeBCexp[j]
    lllamplitudeBCcontr[j]<-aamplitudeBCcontr[j]
  }
} else {
  lllengthBCexp<-0
  lllengthBCcontr<-0
  lllengthBC<-0
  lllamplitudeBCexp<-0
  lllamplitudeBCcontr<-0
}

statlllengthBCexp[1,pt]<-mean(lllengthBCexp)
statlllengthBCexp[2,pt]<-sd(lllengthBCexp)
statlllengthBCexp[3,pt]<-median(lllengthBCexp)
statlllengthBCexp[4,pt]<-min(lllengthBCexp)
statlllengthBCexp[5,pt]<-max(lllengthBCexp)
statlllengthBCexp[6,pt]<-quantile(lllengthBCexp,c(0.25), type = 1)
statlllengthBCexp[7,pt]<-quantile(lllengthBCexp,c(0.75), type = 1)

statlllengthBCcontr[1,pt]<-mean(lllengthBCcontr)
statlllengthBCcontr[2,pt]<-sd(lllengthBCcontr)
statlllengthBCcontr[3,pt]<-median(lllengthBCcontr)
statlllengthBCcontr[4,pt]<-min(lllengthBCcontr)
statlllengthBCcontr[5,pt]<-max(lllengthBCcontr)
statlllengthBCcontr[6,pt]<-quantile(lllengthBCcontr,c(0.25), type = 1)
statlllengthBCcontr[7,pt]<-quantile(lllengthBCcontr,c(0.75), type = 1)

statlllengthBC[1,pt]<-mean(lllengthBC)
statlllengthBC[2,pt]<-sd(lllengthBC)
statlllengthBC[3,pt]<-median(lllengthBC)
statlllengthBC[4,pt]<-min(lllengthBC)
statlllengthBC[5,pt]<-max(lllengthBC)
statlllengthBC[6,pt]<-quantile(lllengthBC,c(0.25), type = 1)
statlllengthBC[7,pt]<-quantile(lllengthBC,c(0.75), type = 1)

statlllamplitudeBCexp[1,pt]<-mean(lllamplitudeBCexp)
statlllamplitudeBCexp[2,pt]<-sd(lllamplitudeBCexp)
statlllamplitudeBCexp[3,pt]<-median(lllamplitudeBCexp)
statlllamplitudeBCexp[4,pt]<-min(lllamplitudeBCexp)
statlllamplitudeBCexp[5,pt]<-max(lllamplitudeBCexp)
statlllamplitudeBCexp[6,pt]<-quantile(lllamplitudeBCexp,c(0.25), type = 1)
statlllamplitudeBCexp[7,pt]<-quantile(lllamplitudeBCexp,c(0.75), type = 1)
```

```
  statlllamplitudeBCcontr[1,pt]<-mean(lllamplitudeBCcontr)
  statlllamplitudeBCcontr[2,pt]<-sd(lllamplitudeBCcontr)
  statlllamplitudeBCcontr[3,pt]<-median(lllamplitudeBCcontr)
  statlllamplitudeBCcontr[4,pt]<-min(lllamplitudeBCcontr)
  statlllamplitudeBCcontr[5,pt]<-max(lllamplitudeBCcontr)
  statlllamplitudeBCcontr[6,pt]<-quantile(lllamplitudeBCcontr,c(0.25), type = 1)
  statlllamplitudeBCcontr[7,pt]<-quantile(lllamplitudeBCcontr,c(0.75), type = 1)

  statBCcount[1,pt]<-mean(BCcount)
  statBCcount[2,pt]<-sd(BCcount)
  statBCcount[3,pt]<-median(BCcount)
  statBCcount[4,pt]<-min(BCcount)
  statBCcount[5,pt]<-max(BCcount)
  statBCcount[6,pt]<-quantile(BCcount,c(0.25), type = 1)
  statBCcount[7,pt]<-quantile(BCcount,c(0.75), type = 1)



#} #the end of all (for all parameters)

save.image(file="C:/Users/zav0032/Desktop/ACE model/Rscripts_ACE/ACE_baseline_model.RData")
save.image(file="F:/ACE model/Rscripts_ACE/ACE_baseline_model.RData")
```